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POLYELECTROLYTE DOSAGE CONTROL SYSTEM FOR WATER FILTRATION,(U)

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(6) POLYELECTROLYTE DOSAGE CONTROL SYSTEM FOR WATER FILTRATION

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FOREWORD

Funding for this work was provided by the U.S. Army Mobility Equipment Research and Development Command at Fort Belvoir, Virginia. The Project Number is DAAK70-80-0031. The Contracting Officer's representative is Maurice Pressman. This work was done under the supervision of Richard H. Snow. Edward Fochtman and G. C. Sresty have provided input into this work. Sam Shelfo performed most of the experimental work.

The views, opinions, and/or findings contained in the report are those of the author(s) and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other documentation.

Respectfully submitted,

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SUMMARY

The purpose of this investigation was to evaluate five proposed methods for polyelectrolyte dosage control. These methods were: Sedimentation Potential, Turbidity Tiration, Turbidity Correlation, Filtrate Turbidity, and Filter Streaming Potential.

The five proposed methods were investigated using the bench scale sand filters. Both synthetic and natural water samples were used. The experimental program consisted of three phases. The optimum polyelectrolyte dosage for sand filtration operation were established in the first phase of the study. The five proposed methods were then evaluated in the second phase of the study. The most promising methods were studied in detail in the third phase. A conceptual design of the best alternative(s) was to be the outcome of the report.

Both turbidity titration and turbidity correlation were found to be ineffective in predicting the optimum polyelectrolyte dosage. They were eliminated from further study. Filter streaming potential did not give a clear indication of the optimum polyelectrolyte dosage when the sand particles were coated with polyelectrolyte. Furthermore, the method failed to predict the optimum polyelectrolyte dosage when the water was highly heterogeneous. Thus, it was decided that this method did not provide a viable means for polyelectrolyte dosage control.

The investigation has produced two viable methods for polyelectrolyte dosage control. Of these two methods, filtration turbidity could be adapted to an on-line continuous system. Sedimentation potential is essentially a batch system and would require further work to develop it into a continuous system. Detailed designs and further developmental work is recommended on both of these methods.

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INTRODUCTION

Polyelectrolytes have been used with much success in improving the efficiency of multimedia filters used in the direct filtration of raw water. Since the inception of their use, however, the problem has existed as to how to set the dosage of the polyelectrolyte to achieve maximum turbidity and suspended solids removal efficiency and longest filter run. Much study has been devoted to the development of stoichiometric relationships between the polyelectrolyte dosage and various constituents in the raw water. However, the characteristics of each raw water source are diverse and vary geographically as well as seasonally. The most common method for selecting the optimum polyelectrolyte dosage has been the jar test. This is a batch laboratory test that does not lend itself to on-line control.

A. PURPOSE OF INVESTIGATION

The filtration unit for MERADCOM is part of a larger mobile system which incorporates reverse osmosis and chlorination units for the upgrading of raw water sources to potable water quality. The use of this system requires its operation in remote areas by relatively unskilled personnel. Therefore, the purpose of this investigation was to evaluate various methods for automatic polyelectrolyte dosage control. A conceptual design of a dosage control system would be defined based on the outcome of this investigation.

The system should be easy to operate and requires a minimum of additional parts. An on-line, continuous, automatic system is the ideal.

B. SCOPE OF WORK

Five methods were proposed by IITRI as possibilities for polyelectrolyte dosage control systems. They were: Sedimentation Potential, Turbidity Titration, Turbidity Correlation, Filtrate Turbidity, and Filter Streaming Potential.

The initial phase of this investigation was to review the information on the application of polyelectrolyte in sand filtration. From this review, the experimental program was directed and planned. Preliminary experiments were done on general sand filtration and on all the propsed dosage control methods to determine which of the methods were workable and appeared favorable for further evaluation. Laboratory experiments were done with both synthetic and natural waters.

The most promising methods, determined from the laboratory studies of all the methods, were studied in depth. The final outcome of this investigation was conceptual design, of the selected methods, for polyelectrolyte dosage control.

C. OBJECTIVES OF PROGRAM

The objectives of this investigation were to develop an automated or simplified method of polyelectrolyte dosage control for the enhancement of the multi-media filter efficiency in removing turbidity and suspended solids from the raw water. With an increased solids removal efficiency, two treatment objectives were to be met. These were: an increased time before backwash of the multimedia sand filter, meaning a better utilization of the available filter media, and a longer life for the cartridge filter downstream from the multi-media filter, meaning less replacement, therefore, less parts to be taken into the field. The method which was to be developed for polyelectrolyte dosage control was to be a method which would be fast, easy to operate and require few additional parts.

THEORETICAL INVESTIGATION

The removal of particulate matter from water by filtration has been classified into two steps (Herzig et al 1970; Ives 1970; O'Melia and Stumm 1967; O'Melia and Crapps 1964): first, the transport of the particle to the filter surface and second, the subsequent attachment. The first step involves physical phenomena such as sieving, sedimentation, inertial impingement, interception and Brownian diffusion. The second step includes electrokinetic phenomena and chemical effects. For large particles (>30 μm) the physical phenomena are controlling, while the electrochemical phenomena are controlling for the small (<1 μm) particles.

A. THE EFFECT OF POLYELECTROLYTE ON THE FILTRATION PROCESS

Glaser and Edzwald (1979) described experimental effects of polyelectrolytes on filtration of very fine (3 to 10 nm) colloids, especially humic acids. An optimum dosage of polyelectrolyte is observed, and it coincides with the optimum in the jar test. It is believed that the polyelectrolyte reduces charge bewteen the colloid particles, and this affects filtration in the following way. Assuming that the filter media is soon coated by colloid particles, then further colloid particles can deposit on those already present, if the charge is reduced. This is the same condition needed for destabilizing particles in the jar test, which explains the correspondence between these two effects.

Wnek (1974) discussed the two steps of filtration, with particular emphasis on the electrokinetics effects. He pointed out the importance of pH, polyelectrolyte concentration, and ionic strength of the system. Under some conditions described by Wnek (1974), if the zeta potential is adjusted for maximum initial particle removal, then the particles will deposit only in the top of the bed. The pressure drop builds up rapidly, and the filter cycle is short. If the zeta potential is displaced from this point somewhat, then particles will be deposited through a greater bed depth, although the effluent will still be clear. This allows long filters runs before backwashing.

B. DISCUSSION OF POSSIBLE METHODS FOR POLYELECTROLYTE DOSAGE CONTROL

There have been few published attempts to control polyelectrolyte for filtration.

Black, et. al., (1965) used radioactive-labeled polyelectrolyte to study the destabilization of dilute colloidal clay suspension under different conditions of pH, ionic strength, colloid concentration, and agitation. They found that the colloid adsorbed 85% of the polyelectrolyte in 30 seconds. This indicates that measurements made just upstream from the filter can be used to control flocculation, and hence filtration. However, our experience shows that in some cases zeta potential requires hours to come to final equilibrium.

Priesing, et. al., (1966) reported the use of streaming current measurement to control the amount of polyelectrolyte added to a raw sewage treatment system. A side stream of the raw sewage was mixed with polymer and passed through the streaming current meter. The dosage was controlled to maintain the streaming current at zero. The main wastewater stream was dosed proportionally. The major problem with this system is the reliable and continuous measurement of streaming current. Although Leeds and Northrup Company introduced a streaming current meter in 1967, it has since been withdrawn from the market.

Wnek (1974) suggested the use of filter streaming potential to monitor the filter performance.

On the basis of current knowledge of the problem, five approaches to the development of a method for the control of polyelectrolyte dosage were suggested. They were:

- Sedimentation Potential
- Turbidity Titration
- Turbidity Correlation
- Filtrate Turbidity
- Filter Streaming Potential

Basic concepts of the five methods proposed and their background information are given in the following sections.

Sedimentation Potential

The use of electrokinetic phenomenon to predict filter performance was suggested by Sennet and Olivier (1965). Some investigators had previously discovered that the optimum filtration of Wyoming bentonite was closely correlated with a reduction in the zeta potential (Sennet and Olivier 1965).

Sedimentation potential is defined as the potential developed when suspended particles are made to flow through an aqueous media. The particles can be induced to move in response to a pressure gradient or an applied potential difference. A set-up where electrodes immersed in the liquid over a particular length can be applied to measure the zeta potential of the particles. The potential developed by the particles moving through the zone is known as the Dorn effect and is described by the following equation:

$$E_d = \frac{D\zeta}{3\eta\lambda} r^3 (\rho-\rho') ng \qquad (1)$$

where E_d = the e.m.f. produced by particles falling through a suspending medium.

D	= Dielectric constant of the media,
ζ	= zeta potential,
η	= visocity,
r	= particle radius,
λ	= specific conductance of the media,
$(\rho-\rho')$	= difference in specific quanity,
n	= particle concentration, and
g	= gravitational acceleration.

This equation shows that sedimentation potential depends on the particle size and zeta potential. When the polyelectrolyte is added to the water, the particles will agglomerate and settle, and the sedimentation potential will increase even though the zeta potential of the particles is reduced by the addition of polyelectrolyte.

The above reasoning suggests that the polyelectrolyte dosage that results in a maximum sedimentation potential reading should be taken as the optimum dosage for filtration application.

Turbidity Titration

One of the objectives of adding polyelectrolytes to any raw water stream is to promote agglomeration of the particles through coagulation-flocculation mechanisms. Agglomeration of the particles produces, obviously, larger particles, which are removed with relative ease by the filter media through straining. The traditional test in water treatment to evaluate a coagulant's effectiveness is the jar test. In this test, the turbidity of the raw water

is measured, the polyelectrolyte added and mixed, a brief flocculation period is allowed and the resulting turbidity is measured. Many investigators believe the jar test is a good indication of filter performance. Indeed, in their study of hexametaphosphate for optimizing filter performance, Smith and Medlar (1968) found that conditions or chemicals which promote coagulation also optimize filtration.

Evaluation of the polyelectrolyte dosage, based on before and after turbidity readings, will give some indication that either an overdose or an underdose of polyelectrolyte is occurring. Overdose of polyelectrolyte fails to cause particle agglomeration. This is because the polyelectrolyte adsorbs onto all the active sites of the particles, leaving no sites available for the interparticle bridging.

Adjustment of the polyelectrolyte dosage to produce to optimum coagulation efficiency may be either upwards or downwards.

Turbidity Correlation

The objective of this method is to establish a relationship between the influent turbidity reading and the optimum polyelectrolyte dosage for filtration. Kane, et. al., (1964) proposed an equation in which the optimum polyelectrolyte dosage, determined from the refiltration rate, could be predicted by knowing the solids concentration in the water and the rate of adsorption. This equation is as follows:

$$P_m = \frac{1}{b} + 2\, K_{s1} W + b\, K_{s1}{}^2 W^2 \qquad (2)$$

where P_m = optimum polyelectrolyte concentration value which gives the maximum refiltration rate

b = function of the adsorption and desorption rate constants at the agitation conditions

K_{s1} = grams of polymer adsorbed per grams of solid

W = grams of solid

They found a linear relationship between the optimum polymer dosage and the grams of solid in the solution for experiments with amorphous silica. A square root relationship between the optimum polymer dosage and the solids content with crystalline silica was found. Therefore, it can be concluded

that there should be a correlation between the amount of particles in solution and the optimum polyelectrolyte dosage.

Because the raw water turbidity would be used as a basis for determining optimum polyelectrolyte dosage for filtration, a problem might result when the turbidity is not linearly related to the suspended solids concentration. This can occur if the suspended particles do not effectively scatter or adsorb light. This may be particularly true in the case of the organic compounds present in natural surface waters. Since the method is so simple, however, it seems worthwhile to try it.

Filtrate Turbidity

This method involves the measurement of the effluent turbidity as the basis for the determination of the optimum polyelectrolyte dosage. As in the previous two methods, an overdose of polymer is as ineffective as an underdose. Previous stuidies indicate that the polymer dosage for optimizing filtration is within a narrow range, similar to the range for coagulation (Yao, et al., 1977).

There are other sources of possible misleading effluent readings other than from an overdose of polymer. Saturation of the filter media with particles can occur if the filter is not backwashed in time. In this case, not only will the particles in the solution pass through, but other particles already sorbed onto the filter media may also be dragged out. The effluent turbidity from the filter under these conditions may be much worse than the influent turbidity.

According to electrokinetic theory, proposed by Wnek (1974), the polyelectrolyte dosage changes the surface characteristics of the filter media to enhance the interparticle attraction of the suspended and sand particles. However, if the charge of the particles to be filtered by the sand media are largely positive, the sand media being negative, the addition of the cationic polyelectrolyte would hinder particle removal rather than enhance it. The effluent turbidity test would not be able to distinguish this until the entire range of dosages had been applied.

Filter Streaming Potential

This method involves the measurement of the charges at the solid-water interface by electrodes imbedded in the filter media. The potential readout will be correlated with optimum filter performance. Measurement of the filter streaming potential can be visualized as a continuous measurement of zeta potential. The Helmholtz-Smoluchowski equation related zeta potential with filter streaming potential as follows (Fuerstenau, 1956):

$$\zeta = \frac{4\Pi n}{D} \frac{EK'}{P} \tag{3}$$

where $K' = c/r = \dfrac{\text{measured resistance across plug,}}{\text{cell constant}}$

E = filter streaming potential

P = pressure

From this equation, when the filter streaming potential is negative, the zeta potential will be negative also. The phenomenon of filter streaming potential is hypothesized to be caused by a charge displacement which takes place when a liquid is forced past a solid (Sennet and Olivier, 1965).

Hunter and Alexander (1963), in their experiments of the adsorption of kaolinite onto silica, found the filter streaming potential measurements unsuccessful because the surface characteristics of the kaolinite and the sand were similar. After the addition of cetyltrimethyl ammonium ion (+), the zeta potential of the sand particles changed from positive to negative, and the removal efficiency of kaolinite particles by the silica increased.

Traditionally filter streaming potential has been measured with the use of a horizontal porous plug, with both sides under pressure and containing electrodes. A 4 cm long plug was used in one study and the flow of the conductivity water was either from left to right or right to left (Hunter and Alexander, 1963).

EXPERIMENTAL PROGRAM

A. EXPERIMENTAL APPARATUS

The schematic diagram of the filtration system used in this investigation is shown in Figure 1. The basic elements of this system include:

- sand filter
- dual-channel, variable-speed peristaltic pump
- piezometer board
- rotameters
- raw water reservoir
- polyelectrolyte solution reservoir
- filtrate reservoirs

Detailed description of these elements are presented in Appendix A.

B. MATERIAL PREPARATION

Preparation of materials used in this investigation is presented in Appendix B.

C. EXPERIMENTAL DESIGN

A three-phase experimental program was designed to carry out the investigation. A detailed discussion on each phase of the experimental program is presented as follows.

Phase I. General Studies

The first phase of the experimental design included general experiments designed to determine which parameters were important in analyzing the filter performance. All the experiments were done using the 15 in. sand filter. A summary of the operating conditions of this filter is presented in Table 1.

TABLE 1. OPERATING CONDITIONS OF THE 15 in. SAND FILTER

Filter Loading Rate (gpm/ft^2)	3.4
Sand Bed Depth (inches)	15.0
Filter Run (minutes)	180.0
Temperature	Room Temperature

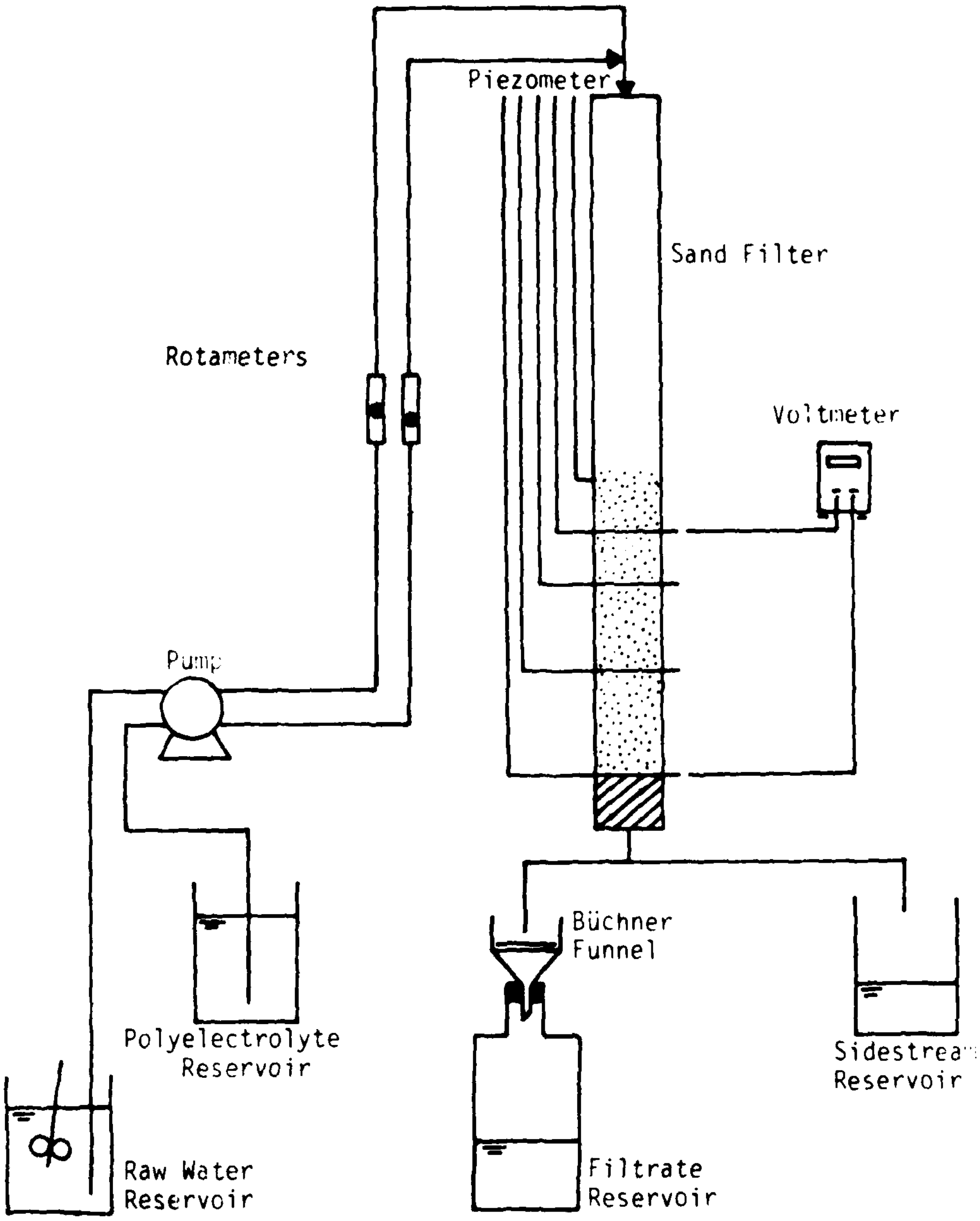


Figure 1. Experimental apparatus.

To determine the effectiveness of the sand filter in treating different types of water, synthetic and natural waters were used. Synthetic water samples with influent turbidities of 43, 85, 150, and 200 FTU's were prepared as described in Section B. In addition to this, three natural water samples taken at different locations were also used. At each influent turbidity value, polyelectrolyte dosages from 0 to 5 mg/l were applied. The dilute polyelectrolyte solution feed rate to the sand filter was set at 10% of the raw water feed rate. The required polyelectrolyte concentration was prepared accordingly.

The criteria for establishing the optimum polyelectrolyte dosage was in terms of effluent turbidity and suspended solids removal and filter run length. Various parameters affecting the filter performance were monitored during each experimental run. Parameters monitored and their sampling frequencies are summarized in Table 2.

TABLE 2. PARAMETERS MONITORED AND THEIR SAMPLING FREQUENCIES IN PHASE I. STUDY

Parameters	Influent	Effluent	Sand Filter	Sampling Frequency
Turbidity	x	x		Influent: Once per run Effluent: Every 15 min
Suspended Solids	x	x		once per run
Alkalinity	x			once per run
pH	x	x		once per run
Temperature	x			once per run
Pressure Drop			x	every 15 min
Conductivity	x	x		once per run

Phase II. Evaluation of the Proposed Polyelectrolyte Dosage Control Methods

In this phase of the investigation, five proposed polyelectrolyte dosage control methods were evaluated based on the optimum polyelectrolyte dosage determined in Phase I for a given set of operating conditions. The evaluation of turbidity correlation, filtration turbidity, and filter streaming filter methods was conducted simultaneously with those measurements taken in Phase I. Separate studies were done on sedimentation potential and turbidity titration methods after the work in Phase I was completed.

Phase III. Detailed Studies on the Most Promising Methods

Based on the outcome of Phase II study, those control methods which appeared promising were further evaluated. The outcome of this phase of the investigation was used as a basis for the conceptual design of the polyelectrolyte dosage control system.

D. ANALYTICAL PROCEDURES

Whenever possible, analytical procedures used in this investigation were performed in accordance with Standard Method or published EPA procedures. The analytical procedures involved in the measurements of sedimentation potential and filter streaming potential followed those reported in the literature. Discussion of the analyses and the procedures involved in this investigation are presented in Appendix C.

RESULTS AND DISCUSSION

A. GENERAL STUDIES

In this phase of study, an attempt was made to determine the optimum polyelectrolyte dosage based on the criteria of best turbidity and suspended solids removal, and longest filter run. For this purpose, effluent turbidity and pressure drop across the sand bed were monitored at 15 minute intervals in each experimental run. The removal of suspended solids by the sand filter was determined by comparing the weight of suspended solids accumulated on the filter paper placed in the Büchner funnel at the filter effluent end and the total weight of suspended solids pumped into the sand filter for each experimental run.

Examination of the experimental data collected in these studies indicates that the effluent turbidities at different time intervals are relatively constant through the entire filter run, regardless of the variations in influent turbidity, the types of water, and the polyelectrolyte dosages. Typical examples of this observation are shown in Figures D-1 and D-2 (Appendix D) for synthetic and natural water samples, respectively. Based on this observation, it was decided to use the average effluent turbidity (which is the turbidity of the sand filter effluent collected in the sidestream reservoir for the entire filtration run) as the parameter for determining the effect of polyelectrolyte on the sand filtration performance.

The information presented (Table E-1 and Figures D-3 and D-4) clearly shows there is a range of polyelectrolyte dosages for which the effluent turbidity reaches minimum level. Furthermore, the removal of suspended solids by the sand filter is also maximized in this range of polyelectrolyte dosages (Table E-2). Thus, it is reasonable to conclude that maximum removal of turbidity and suspended solids of raw water (synthetic and natural) are occurring in the same range of polyelectrolyte dosages.

One of the criteria for determining optimum polyelectrolyte dosage is longest filter run. Each experimental run was operated for 180 minutes and it was terminated if pressure drop across the sand bed exceeded 60 in. before 180 minute run was over. The time at which the run was terminated was then taken as the length of filter run. The lengths of filter runs obtained

this phase of study are summarized in Table E-3.

From the information reported in Tables E-1, E-2, and E-3, the optimum polyelectrolyte dosages are determined for different water samples with different influent turbidity values as compared in Table 3.

TABLE 3. OPTIMUM POLYELECTROLYTE DOSAGES

Water Sample	Optimum Polyelectrolyte Dosages mg/l
Synthetic Water	
43*	2.0-3.5
85	1.5-3.0
150	3.0-4.0
200	3.0-4.0
Natural Water	
Des Plaines River (35)*	0.5-1.0
Lake Michigan (6)	<0.5
Salt Creek (90)	1.0

* Influent turbidity in FTU.

The optimum polyelectrolyte dosages determined in this phase of study will be used as a basis for the evaluation of five proposed methods for polyelectrolyte dosage control.

B. EVALUATION OF THE PROPOSED POLYELECTROLYTE DOSAGE CONTROL METHODS

Sedimentation Potential

Since the sedimentation potential of the particles is proportional to the cube of the particle radius (Sennet and Olivier, 1965), it is conceivable that the polyelectrolyte dosage which induces the optimum flocculation-coagulation of the particles will also result in a maximum sedimentation potential reading, even though the zeta potential of the particles is reduced by the addition of polyelectrolyte. Furthermore, evidence reported in the literature (Glaser and Edzwald, 1979) indicates that maximum flocculation and settling gives best

filtration. The Army has also found that the jar test result correlates reasonably well with the dosage required for filtration. Therefore, the optimum polyelectrolyte dosage for filtration should yield the maximum sedimentation potential reading.

For this purpose, a series of sedimentation potential measurements were taken for all water samples used in this investigation. All the sedimentation potential readings reported in this investigation were obtained from a 1 in. I.D. Plexiglas column equipped with two platinum electrodes 15 in. apart.

Examination of the raw sedimentation potential data shows rapid change occurring in the first two minutes. After that, the readings changed slowly with respect to time (Figure D-5). The phenomena might be caused by the quick initial settling of large particles which induced a rapid change in potential readings. The data shows that sedimentation potential readings taken at different time intervals exhibit a correspondence to polyelectrolyte dosages. In other words, all sedimentation potential readings reach maximum levels when polyelectrolyte dosage is in the range of 2.0 to 3.5 mg/l, regardless of the time the readings were taken. In addition to this, the maximum sedimentation potential readings were obtained in the polyelectrolyte dosage range which results in the maximum turbidity and suspended solids removal (Table 3). The assumption that maximum flocculation and settling corresponds with the best filtration appears to be somewhat validated by this data.

To further verify this assumption, all the sedimentation potential readings taken at 2 minutes were plotted as a function of polyelectrolyte dosages. Figure 3 shows the comparison of the sedimentation potential values at 2 minutes for all the turbidities of the synthetic water. Despite the difference in sedimentation potential values obtained at different influent turbidities, all the curves plotted in Figure 2 show a similar trend, that is, the absolute values of the sedimentation potential readings increase with increasing polyelectrolyte dosages. The absolute sedimentation potential values decrease when an overdose occurs. This provides additional experimental evidence in supporting the assumption discussed previously.

Sedimentation potential was also tested on natural water samples, as shown in Figure 3. The optimum polyelectrolyte dosages predicted by the sedimentation potential measurements and by the sand filtration study (Table 3) correspond

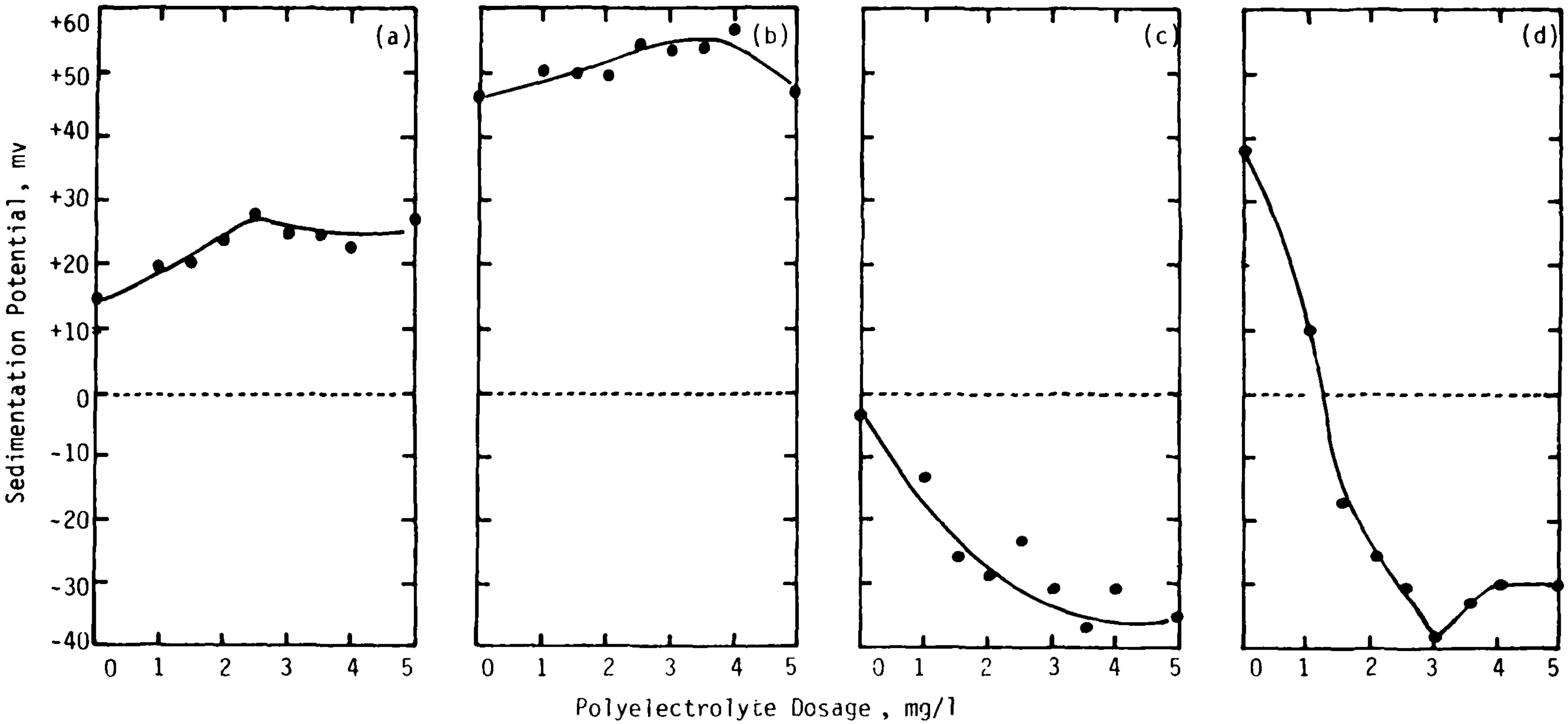


Figure 2. Sedimentation potential taken at 2 minute vs. polyelectrolyte dosages. Synthetic water. Influent Turbidity: (a) 43 FTU, (b) 85 FTU, (c) 150 FTU, (d) 200 FTU.

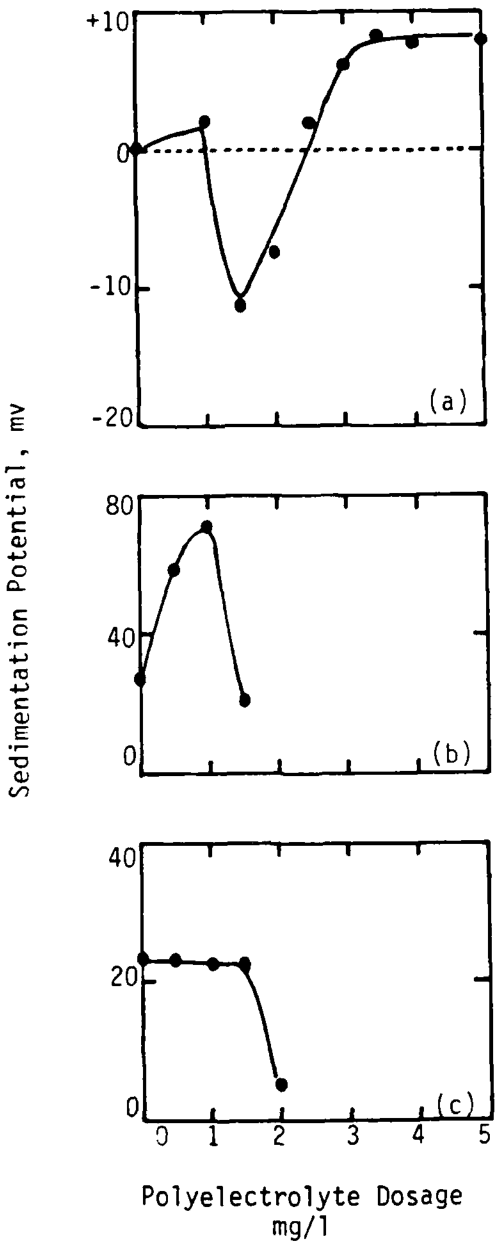


Figure 3. Sedimentation potential readings taken at 2 minutes vs. polyelectrolyte dosages. Natural water.
(a) Salt Creek (Influent Turbidity = 90 FTU)
(b) Des Plaines River (Influent Turbidity = 35 FTU)
(c) Lake Michigan (Influent Turbidity = 6 FTU).

very closely. Table 4 summarizes the comparison of the optimum polyelectrolyte dosages predicted by sedimentation potential measurements and those obtained by sand filtration studies.

TABLE 4. COMPARISON OF THE OPTIMUM POLYELECTROLYTE DOSAGES PREDICTED BY SEDIMENTATION POTENTIAL MEASUREMENTS AND THOSE OBTAINED BY SAND FILTRATION STUDIES.

Water Sample	Optimum Polyelectrolyte Dosage, mg/l	
	Sedimentation Potential	Sand Filtration
Synthetic Water		
43*	2.5-3.5	2.0-3.5
85	2.5-4.0	1.5-3.0
150	3.5	3.0-4.0
200	3.0	3.0-4.0
Natural Water		
Des Plaines River (35)*	1.0	0.5-1.0
Lake Michigan (6)	0.5	0.5
Salt Creek (90)	1.5	1.0

* Influent Turbidity in FTU.

Sedimentation potential provides a sinple, quick, and reliable method for determining optimum polyelectrolyte dosage. The experimental results obtained in this investigation suggest that the maximum sedimentation potential values would be obtained in the polyelectrolyte dosage range which is optimum for filtration. The experimental apparatus and procedure used in this investigation provide an appropriate approach for field application.

Turbidity Titration

The procedure for testing the turbidity correlation has been discussed in the previous section. The experimental results obtained in this study are summarized in Table E-4. There appeared to be no change from the initial turbidity to the polyelectrolyte-dosed turbidity, measured by either Hach Turbidimeter or Price-Phoenix Photometer. This result does not agree with that reported by Smith and Medlar (1968). This might be caused by the insufficient time allowed

for particles to flocculate and coagulate. Positive results leading to the use of the method as a means of polyelectrolyte dosage control were not forthcoming; therefore, further investigation of this method was terminated.

Turbidity Correlation

The optimum polyelectrolyte dosage was determined in the general studies based on the criteria of maximum turbidity and suspended solids removal and longest filter run. The information has been summarized in Tables E-2 and E-3.

The optimum polyelectrolyte dosage is referred to as a range of dosages rather than one particular dosage. The optimum polyelectrolyte dosages for the three natural water samples did not necessarily correlate with the influent turbidity. For example, the optimum polyelectrolyte dosages for these three natural water samples are within 0.5-1.0 mg/l while the influent turbidities vary from 6 to 90 FTU's. The influent turbidities and suspended solids concentrations for natural water samples (Table B-3) do not show a linear relationship; therefore, the theory proposed by Kane, et. al., (1964) does not apply, and influent turbidity cannot be related to the optimum polyelectrolyte dosage. On this basis, no further investigations were undertaken on this method.

Filtrate Turbidity

The experimental data plotted in Figures D-3 and D-4 clearly shows that there is always a range of polyelectrolyte dosages in which both effluent turbidity and suspended solids are minimal. The observations agree with those reported by Yao, et. al., (1971). Filtrate turbidity has a direct relationship with optimum polyelectrolyte dosage, regardless of the influent turbidities and water types. Therefore, it provides a most promising method for dosage control. The only problem applying this method is how to obtain optimum polyelectrolyte dosage in a relatively short period of time. This will be discussed in detail in the next section.

Filter Streaming Potential

Filter streaming potential measurements were done on the 15 in. sand bed using a fresh batch of sand for each run. Examples of the filter streaming potential measurements during the course of a filter run are given in Figures D-6 and D-7 for the synthetic and natural water samples, respectively. The data plotted in these figures shows the change of filter streaming filter

readings at different polyelectrolyte dosages. This demonstrates that the addition of polyelectrolyte to the sand filter changes the electrokinetic properties of the filter.

It is observed by examining the filter streaming potential data that the potential readings are relatively constant 30 minutes after the start of the filter run. Therefore, the average potential values were calculated and plotted as a function of polyelectrolyte dosages for both synthetic and natural water samples. The streaming potential values averaged after 30 minutes for four different synthetic waters (43, 85, 150 and 200 FTU) are presented in Figure 4. The plotted filter streaming potential values show the similar trend (less obvious for Figure 4). The filter streaming potential increases with increasing polyelectrolyte dosage, takes a sharp drop at a dosage of 2.0 to 3.0 mg/l, then takes an upward direction and either approaches zero or some positive values. The sharp drop in filter streaming potential readings occurs within the optimum polyelectrolyte dosage range (Table 3) for four different synthetic water samples. This data does not agree with the findings reported by Hunter and Alexander (1963) where the zeta (filter streaming) potential changed from positive to negative with an increase in filtration efficiency.

Comparison of the streaming potential values for all the natural water samples, that is, the Des Plaines River, Lake Michigan and Salt Creek with polyelectrolyte dosage, is given in Figure 5. Overall, from Figure 5, there appears to be no correlation or means of predicting the optimum polyelectrolyte dosage from the streaming potential data. This may be due to the heterogeneous nature of surface waters.

C. DETAILED STUDIES ON THE MOST PROMISING METHODS

From the results reported in Section B, sedimentation potential, filtrate turbidity, and filter streaming potential appear to be favorable for further study. Results of the sedimentation potential data demonstrate that the optimum polyelectrolyte dosage can be selected in a relatively short time period (2 minutes) by the procedures employed in this investigation. Detailed study was not required because sufficient data was obtained in Phase II. Although the data on the filter streaming potential did not show a clear correspondence between potential values and optimum polyelectrolyte dosages for natural water,

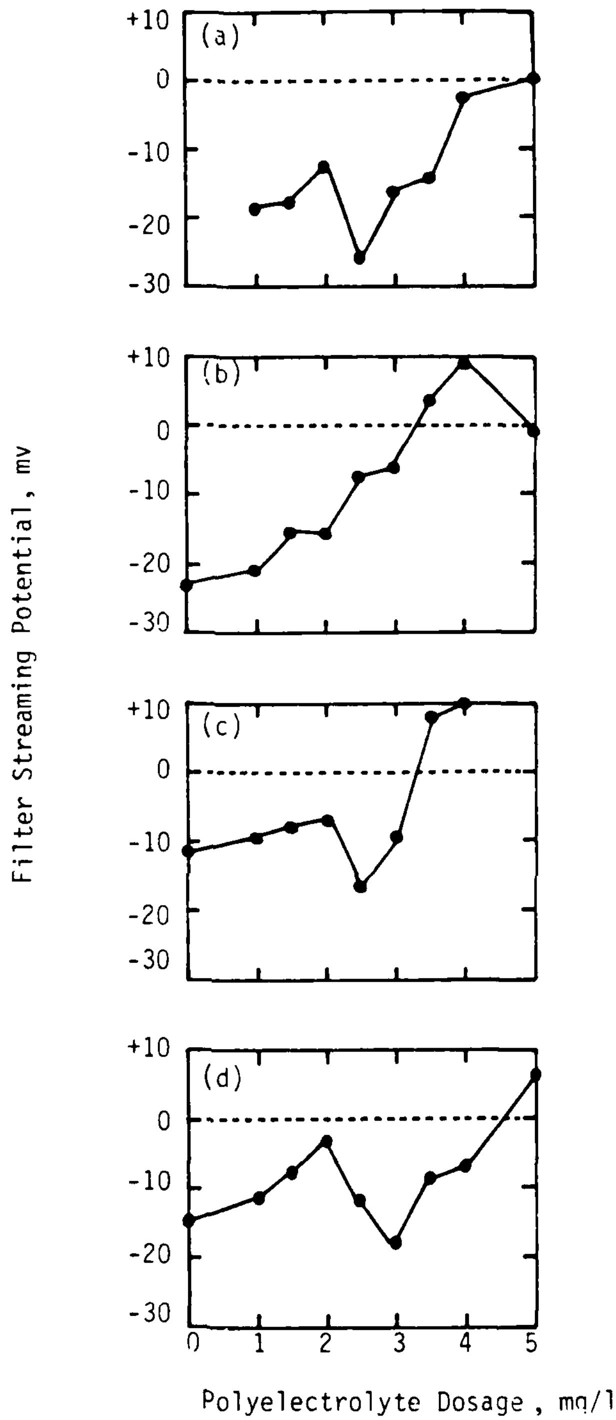


Figure 4. Average filter streaming potential readings vs. polyelectrolyte dosages. Synthetic water Influent Turbidity: (a) 43 FTU, (b) 85 FTU, (c) 150 FTU, (d) 200 FTU.

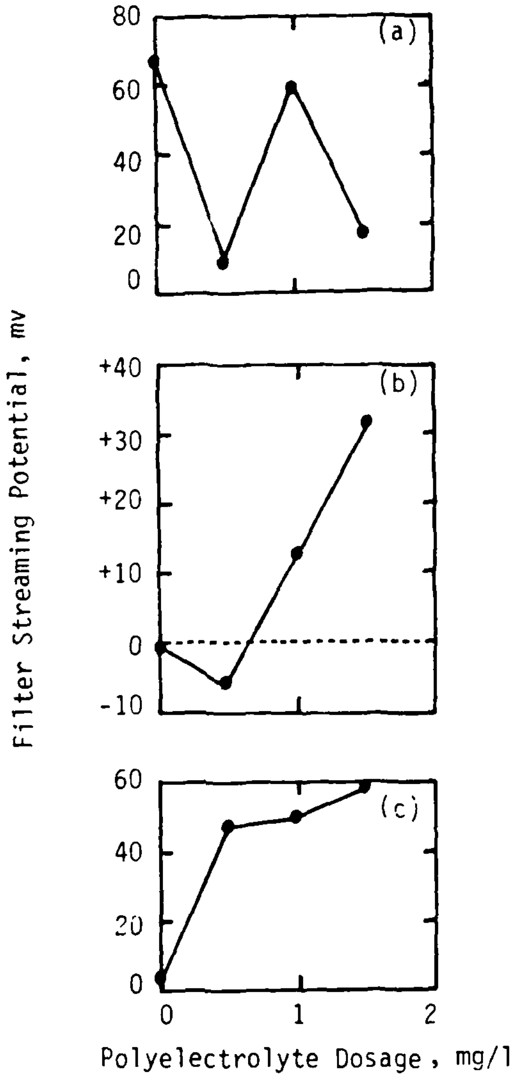


Figure 5. Average filter streaming potential readings vs. polyelectrolyte dosages.
Natural water:
(a) Des Plaines River (Influent Turbidity = 35 FTU)
(b) Lake Michigan (Influent Turbidity = 6 FTU)
(c) Salt Creek (Influent Turbidity = 90 FTU)

the interesting phenomena observed in the synthetic water case (Figure 4) warranted further evaluation. Therefore, both filter streaming potential and filtrate turbidity which appeared to be promising were chosen for further study.

To quicken the response of the sand filter and thus decrease the required time for locating optimum polyelectrolyte dosage, a second sand filter with shallow sand bed depth (3 in.) was constructed and tested. Before the detailed evaluation was done, the performance of this 3 in. sand filter was compared with the 15 in. sand filter. The results are shown in Figure D-8. This figure shows that both sand filters behave similarly, and it is reasonable to conclude that sand bed depth has no effect on the performance of the filter.

With the 3 in. sand filter some modifications of the experimental procedures were made: (1) the filter streaming potential and effluent turbidity readings were taken at 2 minute intervals, and (2) the polyelectrolyte dosages applied to the filter were varied during each filtration run instead of keeping at a constant for the entire run. The latter was done to simulate the operation of a prototype dosage control system. A synthetic water with influent turbidity of 85 FTU and a natural water (taken from the Des Plaines River) with influent turbidity of 90 FTU were used as the samples. Discussion on the results obtained in this phase of the study is given as follows.

The Response of Filtrate Turbidity and Filter Streaming Potential to Various Polyelectrolyte Dosages

The results of this part of the study are plotted in Figures 6 to 11. A fresh batch of sand was used for each run. Filtrate turbidity measurements show a consistent response to polyelectrolyte dosage for both synthetic and natural water samples while filter streaming measurements worked only for synthetic water.

Figure 6 presents the results of a filtration run using the synthetic water in which the polyelectrolyte dosages were monotonically increased from 0 to 5 mg/l, and 6 minutes was allowed between the change of the dosage levels. From this figure, both effluent turbidity and filter streaming potential readings show a similar trend. As the polyelectrolyte dosage increases, both effluent turbidity and filter streaming potential decrease until the polyelectrolyte

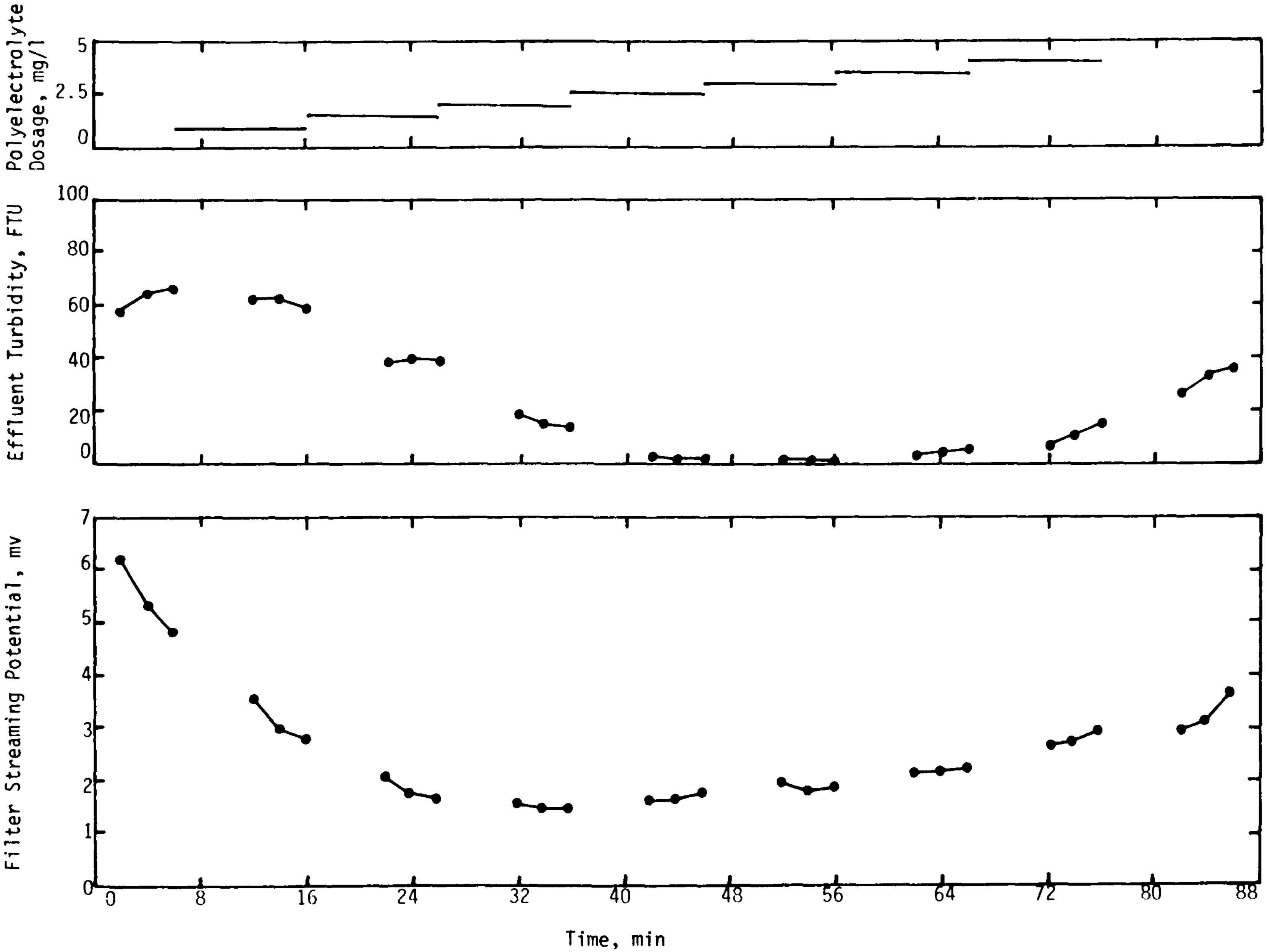


Figure 6. Effluent turbidity and filter streaming potential readings at various polyelectrolyte dosages. Synthetic water (Influent Turbidity = 85 FTU). 3" Sand filter; 6 minutes was allowed between the change of polyelectrolyte doscge.

dosage reaches the range of 2.5 to 3.0 mg/l. Beyond this dosage range, both readings start to increase. This indicates that at the optimum polyelectrolyte dosage, both effluent turbidity and filter streaming potential should reach minimum values.

After this filtration run had been completed, the experimental procedures were modifed again. Instead of allowing 6 minute equalization time between the change of polyelectrolyte dosage, the water accumulated above the sand level was drained immediately after the dosage level was changed. This modification in experimental procedure was followed for the remaining runs to reduce lag time.

Figure 7 shows the responses of effluent turbidity and filter streaming potential to various polyelectrolyte dosages when synthetic water was used. Apparently the change in experimental procedures does not affect the responses of these two parameters. In other words, both readings reach minimum levels in the optimum polyelectrolyte dosage range.

In the next two filtration runs, the sequence of applying polyelectrolyte dosage levels was converging from either low or high level toward median values. The results are presented in Figures 8 and 9. Again, the change in the sequence of applying polyelectrolyte dosages has no effect on effluent turbidity or filter streaming potential. They all reached minimum levels when the optimum polyelectrolyte dosage was applied to the filter.

The experimental results reported in Figure 6 to 9 are for the synthetic water which has relatively uniform characteristics and contains small particles. It seems that both effluent turbidity and filter streaming potential measurements would provide reliable prediction on the optimum polyelectrolyte dosage for filtration.

The two methods were further examined using a natural water which contained large sediment particles. The turbidity was 90 FTU. The results are presented in Figures 10 and 11.

From these figures, effluent turbidity measurements show a response relatively consistent to polyelectrolyte dosages and give a clear indication of the optimum polyelectrolyte dosages. The difference in water characteristics and particle size has no effect on the effluent turbidity response.

In the case of filter streaming potential measurements, the responses are

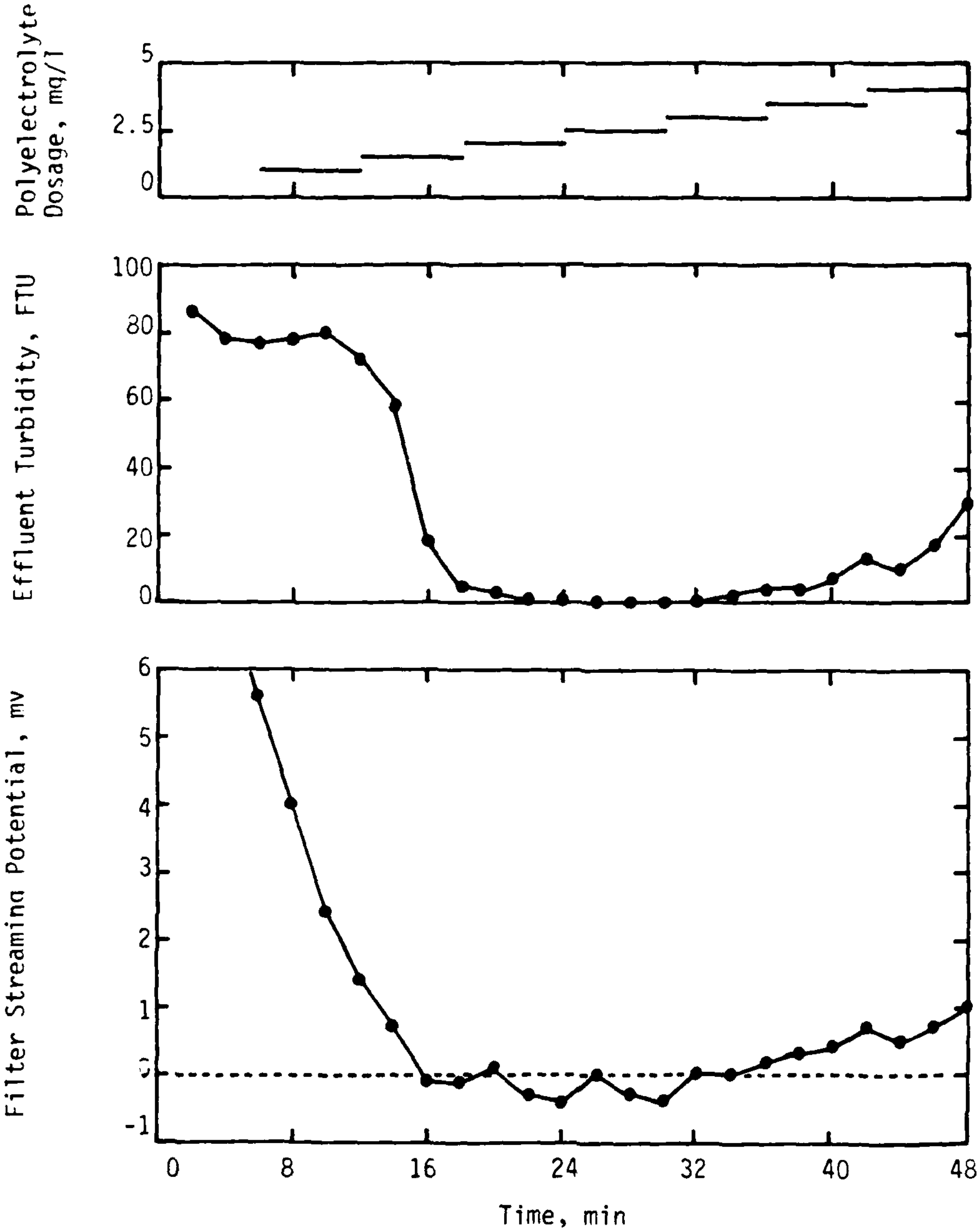


Figure 7. Effluent turbidity and filter streaming potential readings at various polyelectrolyte dosages. Synthetic water (Influent Turbidity = 85 FTU). 3" Sand filter; Water above the sand bed was drained between the change of polyelectrolyte dosage.

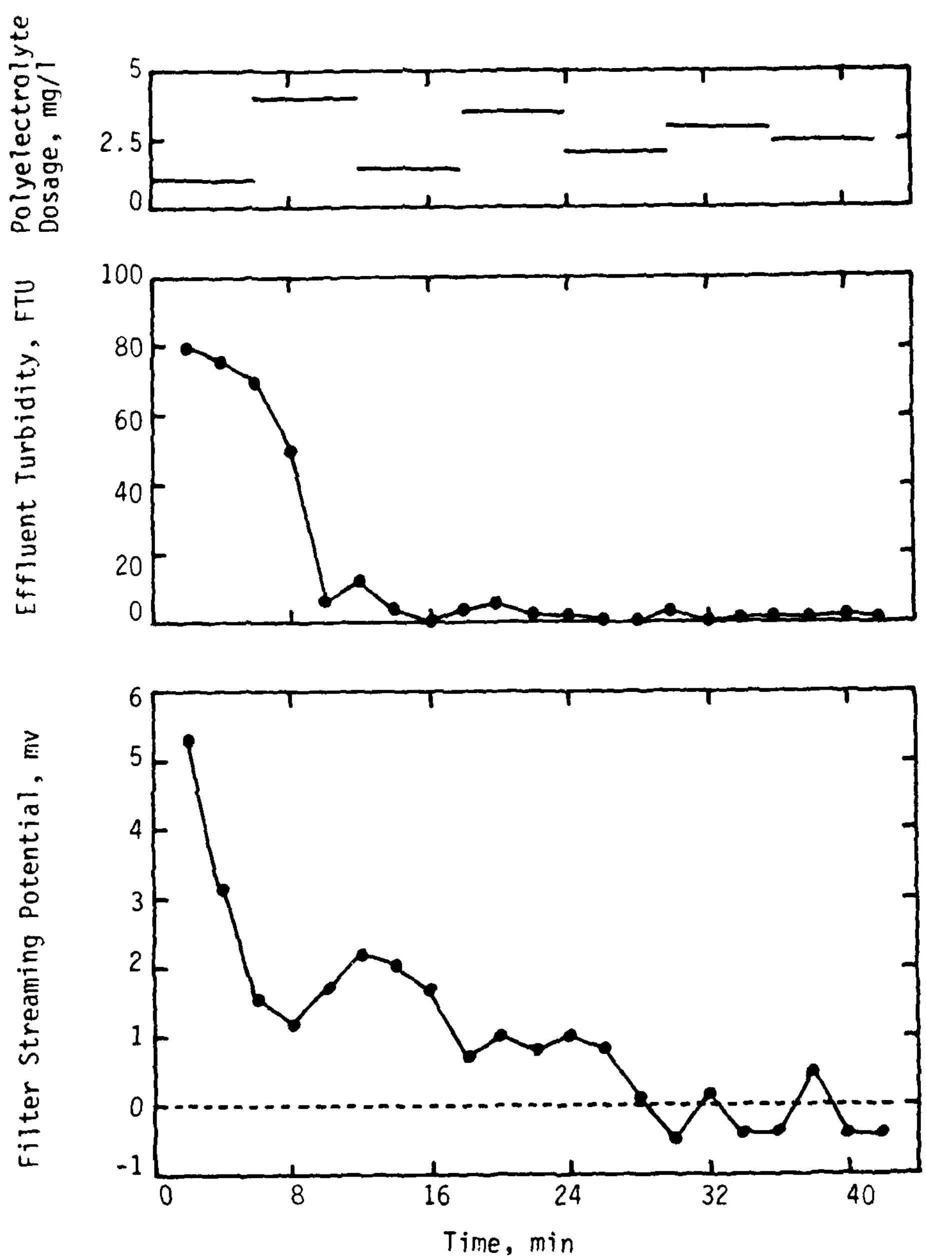


Figure 8. Effluent turbidity and filter streaming potential readings at various polyelectrolyte dosages. Synthetic water (Influent Turbidity = 85 FTU). 3" Sand filter; Water above the sand bed was drained between the change of polyelectrolyte dosage.

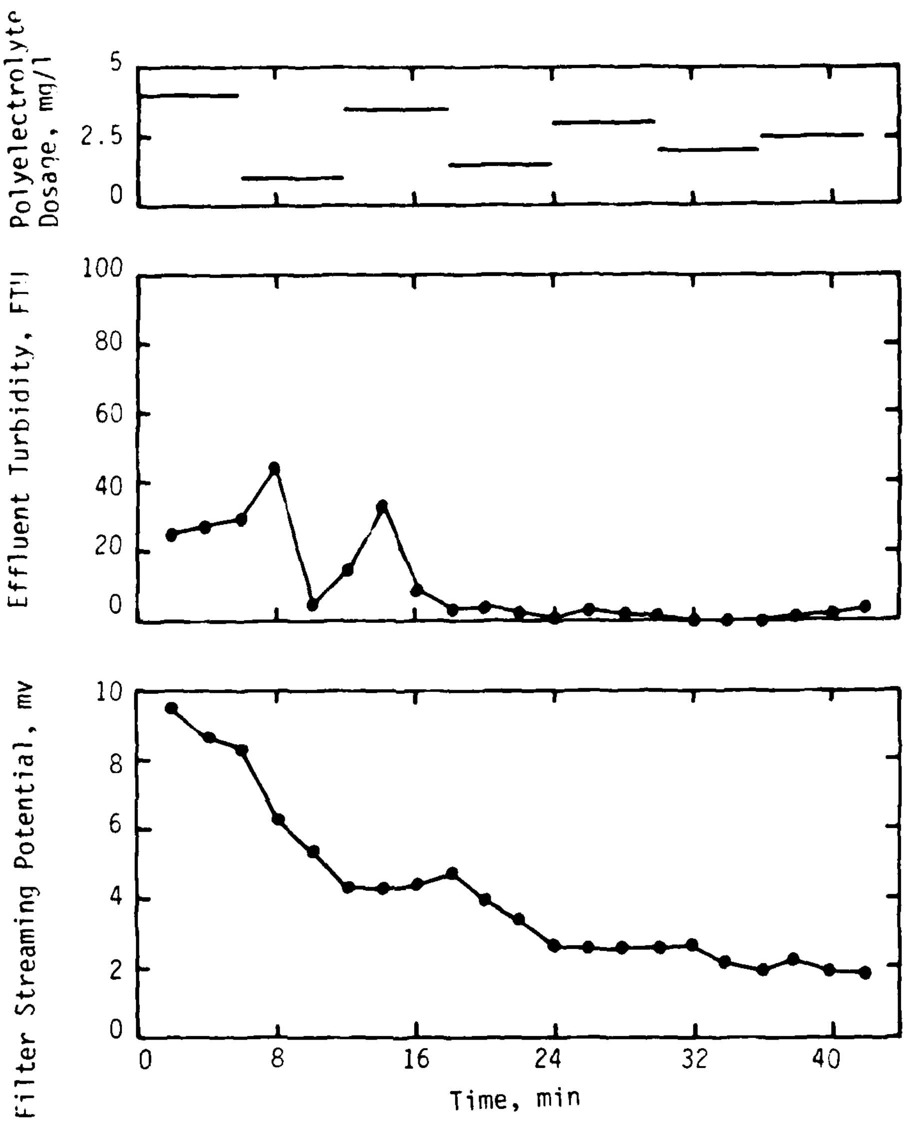


Figure 9. Effluent turbidity and filter streaming potential readings at various polyelectrolyte dosages. Synthetic water (Influent Turbidity = 85 FTU). 3" Sand filter; Water above the sand bed was drained between the change of polyelectrolyte dosages.

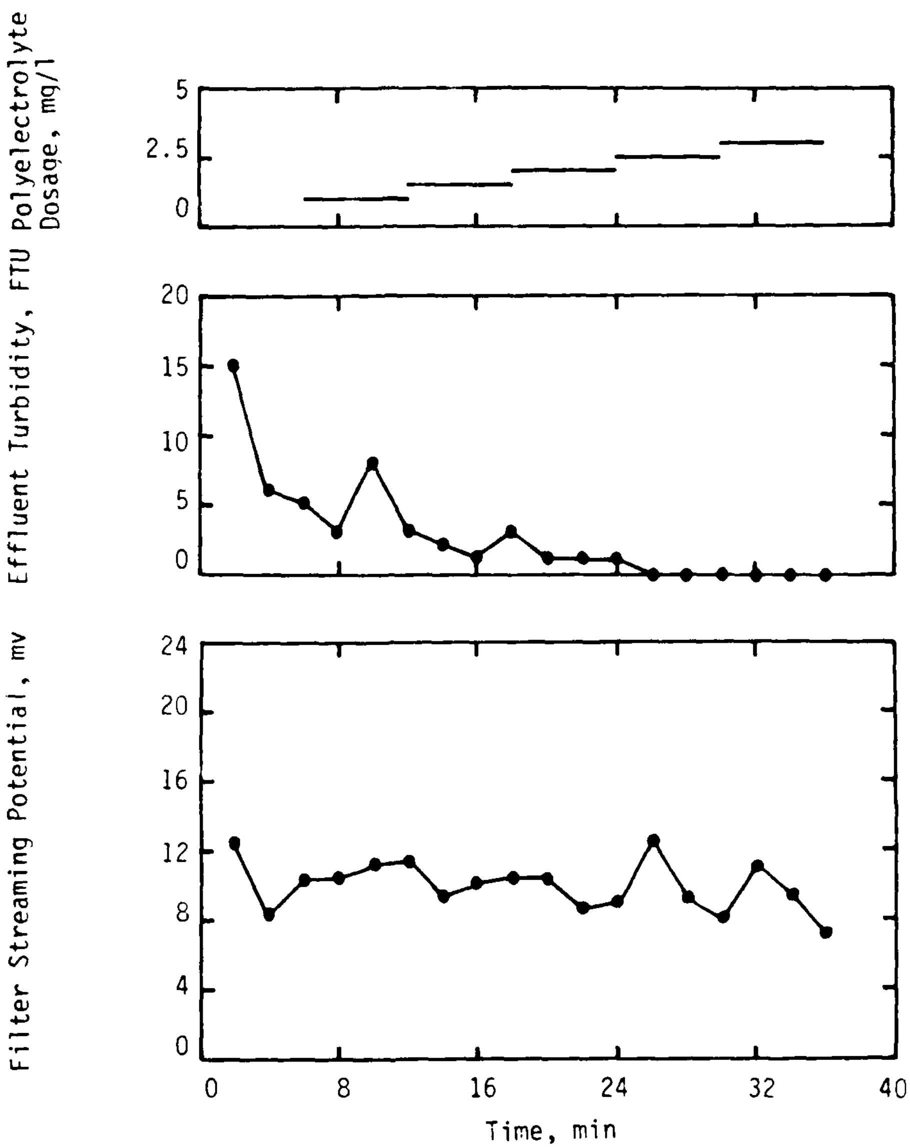


Figure 10. Effluent turbidity and filter streaming potential readings at various polyelectrolyte dosages. Des Plaines River water (Influent Turbidity = 90 FTU). 3" Sand filter; Water above the sand bed was drained between the change of polyelectrolyte dosage.

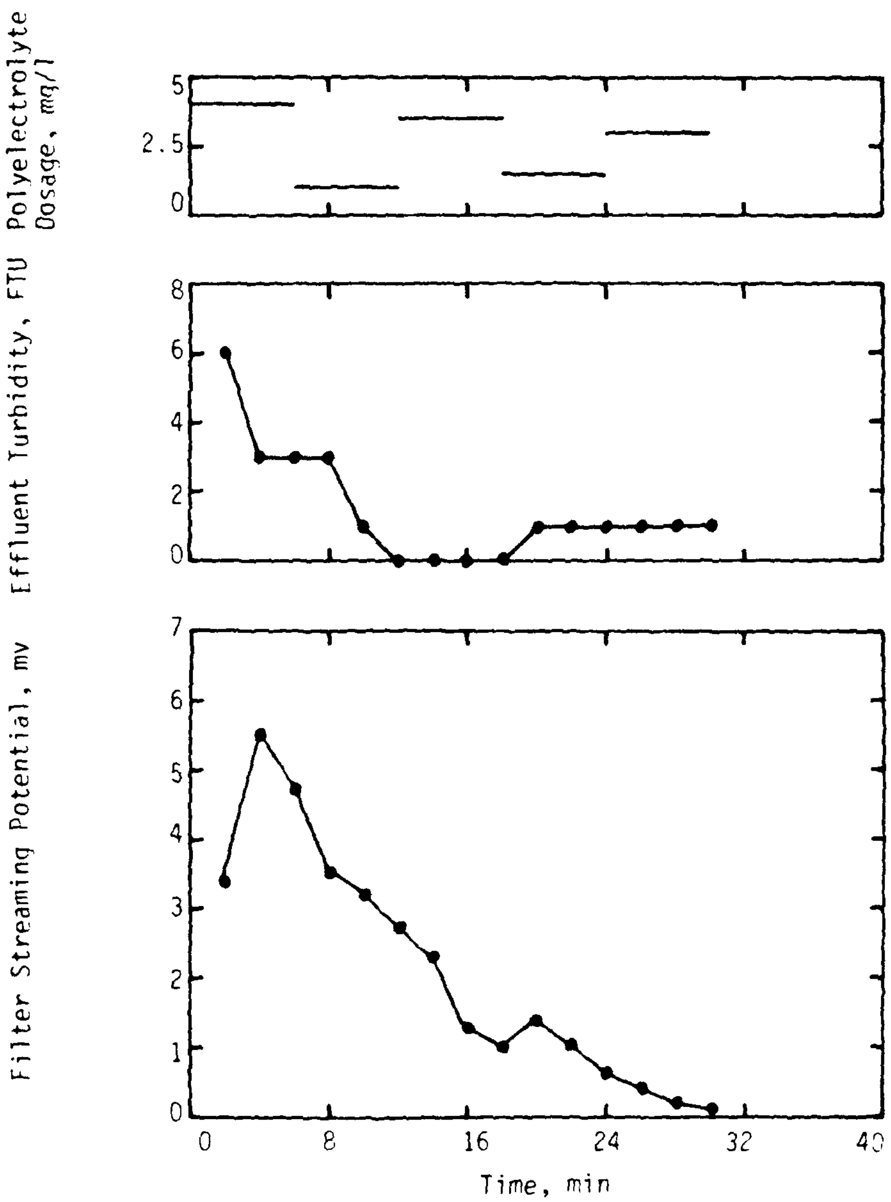


Figure [illegible]. Effluent turbidity and filter streaming potential readings at various polyelectrolyte dosages. Des Plaines River water (Influent Turbidity = 90 FTU). 8" Sand filter; Water above the sand bed was drained between the change of polyelectrolyte dosage.

not as consistent as those observed when synthetic water was used. The filter streaming potential readings were fluctuating between 7 to 13 mv (Figure 10) when polyelectrolyte dosages were increased stepwise from 0 to 3.0 mg/l. When the polyelectrolyte dosage was converging from a high level towards a median level (Figure 11), the filter streaming potential readings decreased continuously and did not correspond to the optimum polyelectrolyte dosage. This inconsistency might be caused by the particle size and other characteristics associated with the natural water used. Some other mechanisms such as straining and interception might exert greater influence on the filter operation and therefore overshadow the electrokinetic mechanism. In this case, filter streaming potential measurement does not give a clear indication of the optimum polyelectrolyte dosage.

Effect of Backwashing on the Responses of Effluent Turbidity and Filter Streaming Potential at Various Polyelectrolyte Dosages

The effects of backwashing on the response of effluent turbidity and filter streaming potential were evaluated in the remaining two filtration runs. After an adjustment of polyelectrolyte dosages had been completed, the sand bed was backwashed for 5 minutes. The sand bed was drained and settled, and the experiments were repeated. Two backwashings were employed in each set of filtration runs. Figures 12 and 13 present the results obtained with the synthetic and natural water samples, respectively.

For both synthetic and natural water samples, the correspondence between effluent turbidity and optimum polyelectrolyte dosage was consistent through the entire filtration run, regardless of the backwashing. This indicates that the effluent turbidity measurement can be applied directly as an on-line control system for the filter. Based on the results plotted in Figures 8 to 11, the optimum polyelectrolyte dosage should be determined within 20 minutes following the procedure employed in this phase of study.

Another interesting fact is that the optimum polyelectrolyte dosage, determined from effluent turbidity measurement using fresh sand, can be chosen for the entire filtration run, even when backwashing is used to regenerate the sand bed. This indicates that one set of measurements taken at beginning of the filtration run will be sufficient.

The responses of the filter streaming potential measurements are somewhat less promising when backwashing is used. Apparently the backwashing only removes the deposit accumulated in the sand bed and has little effect in removing

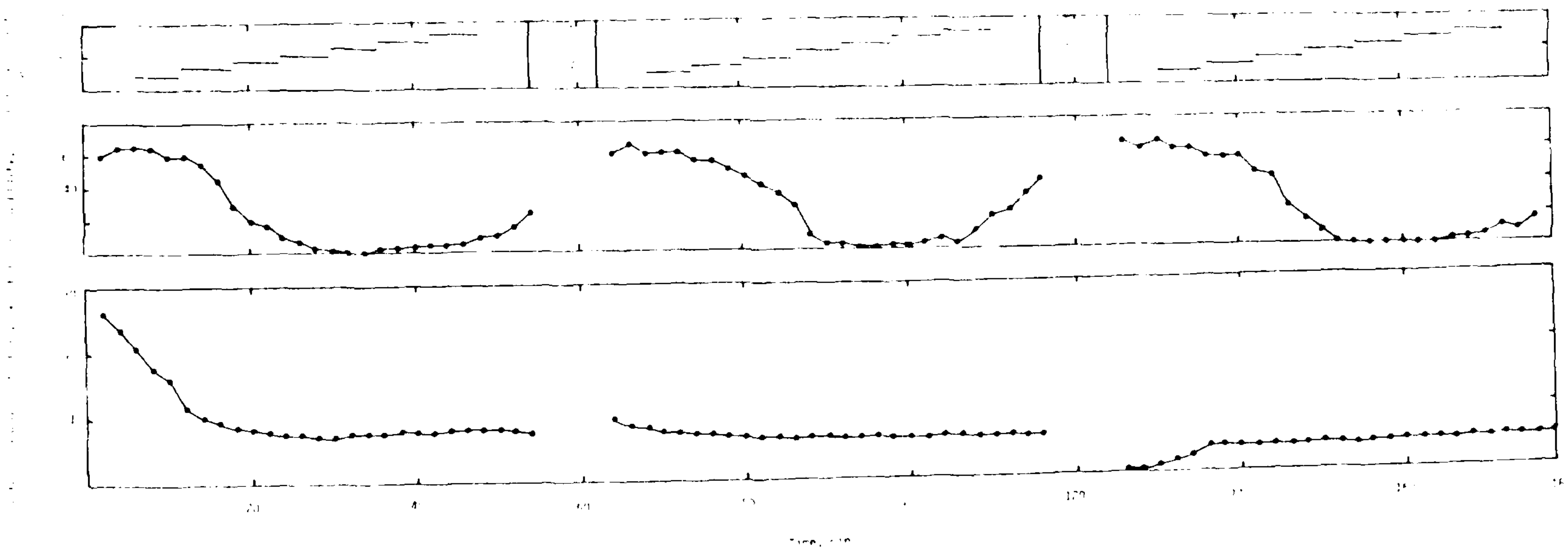


Figure 12. Effluent turbidity and filter potential readings at various polyelectrolyte dosages with backwashing. Synthetic water (Influent Turbidity = 85 FTU).
3" Sand filter; Water above the sand bed was drained between the change of polyelectrolyte dosage.

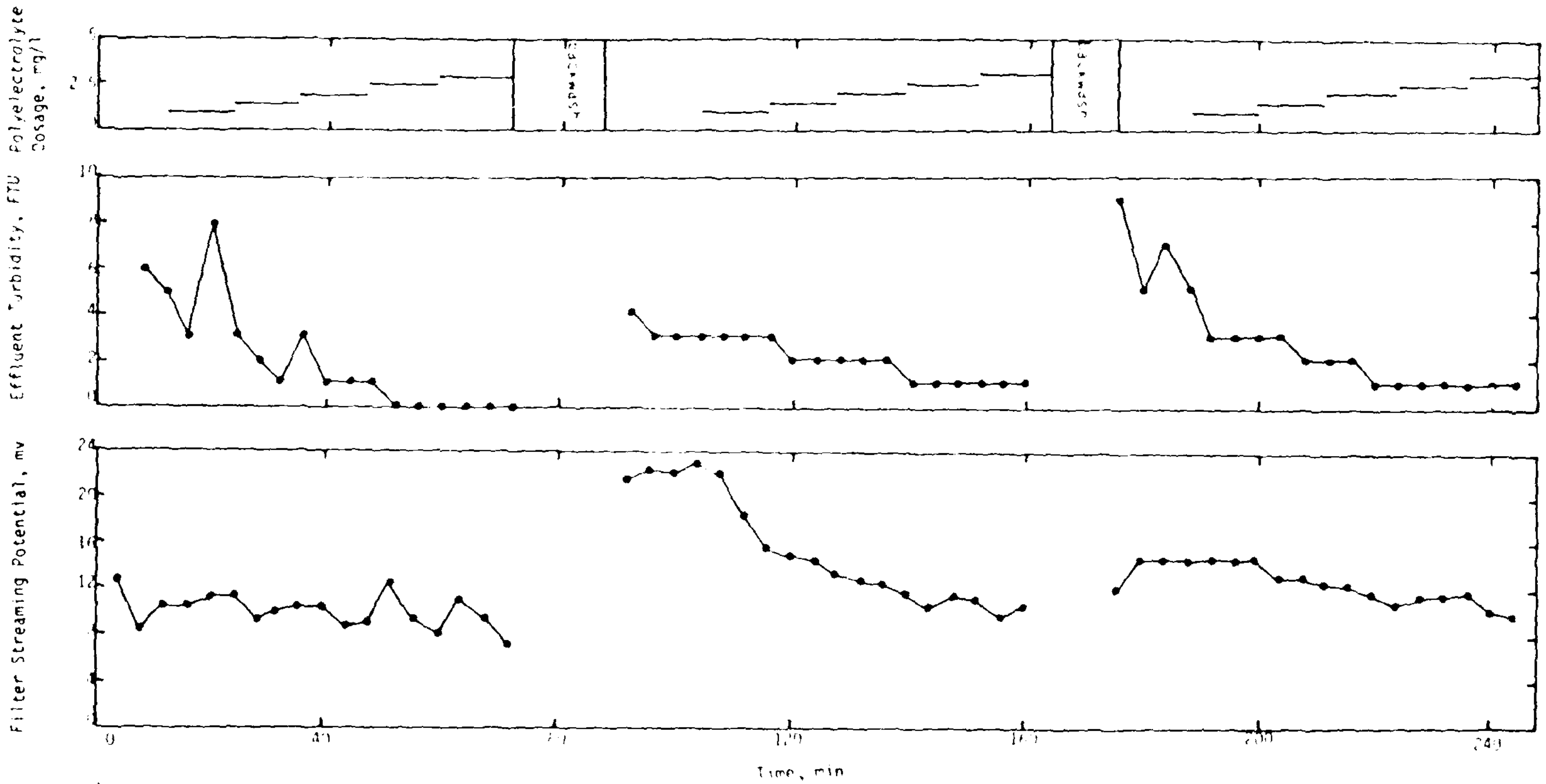


Figure 12. [illegible] turbidity and filter streaming potential readings at various polyelectrolyte [illegible] with backwashing. [illegible] (effluent turbidity = 90 FTU). [illegible] filter, arrow shows the [illegible] change of polyelectrolyte dosage.

polyelectrolyte coated on the sand particles. Thus after the backwashing, the sand filter behaves more or less like the precoated filter instead of the sand filter with fresh sand particles. This difference in electrokinetic properties is reflected by the inconsistent filter streaming potential readings depicted in Figures 12 and 13.

Conclusions

Based on the observations reported, it is indicated that filtrate turbidity is the most promising and reliable method for polyelectrolyte dosage control that can be applied directly as an on-line, automatic control system. A small test filter can be set up beside the filtration unit as part of the automatic control system. Such a small test filter should be appropriate for a quick and reliable determination of the optimum polyelectrolyte dosage.

Sedimentation potential is another viable alternative for determining optimum polyelectrolyte dosage. Since the method is relatively simple and fairly reliable, it seems worth consideration.

Filter streaming potential does not give a clear indication of the optimum polyelectrolyte dosage when the water is highly heterogeneous. In addition to this, the method does not work once the filter media is coated with polyelectrolyte. Positive results leading to the use of this method as a means of polyelectrolyte dosage control for field application are not forthcoming.

D. CONCEPTUAL DESIGN

There are two options for a polyelectrolyte dosage control system. Each option is a different control mechanism and may vary in its applicability to different water sources. The methods include filtrate turbidity and sedimentation potential. Conceptual designs of these will be discussed below.

Filtrate Turbidity

As previously discussed, this method provides the most reliable indication of filter performance. Application of this method to MERADCOM's water treatment system would include the photometric measure of the effluent from a test filter with the adjustment of the polyelectrolyte dosage to minimize the effluent

turbidity. The test filter would be installed beside the MERADCOM filtration unit as shown in Figure 14. A backwash system would be incorporated, which would take backwash water from the effluent line of the main filter. The test filter could be tested for different polyelectrolyte dosages to select the optimum one in a relatively short period of time, as demonstrated in this study.

The procedure for setting the optimum polyelectrolyte dosage with the filtrate turbidity method could be as follows:

1. The filter would be started up with the Chemical Feed Pump on, however, the control valve on the recycle line would be completely open. Under these conditions, there would be little, if any polyelectrolyte dosed into the raw water influent.

2. Based on the effluent turbidity reading from the test filter, the control valve on the polyelectrolyte recycle line would be closed in increments (meaning the dosage to the raw water influent would be increased).

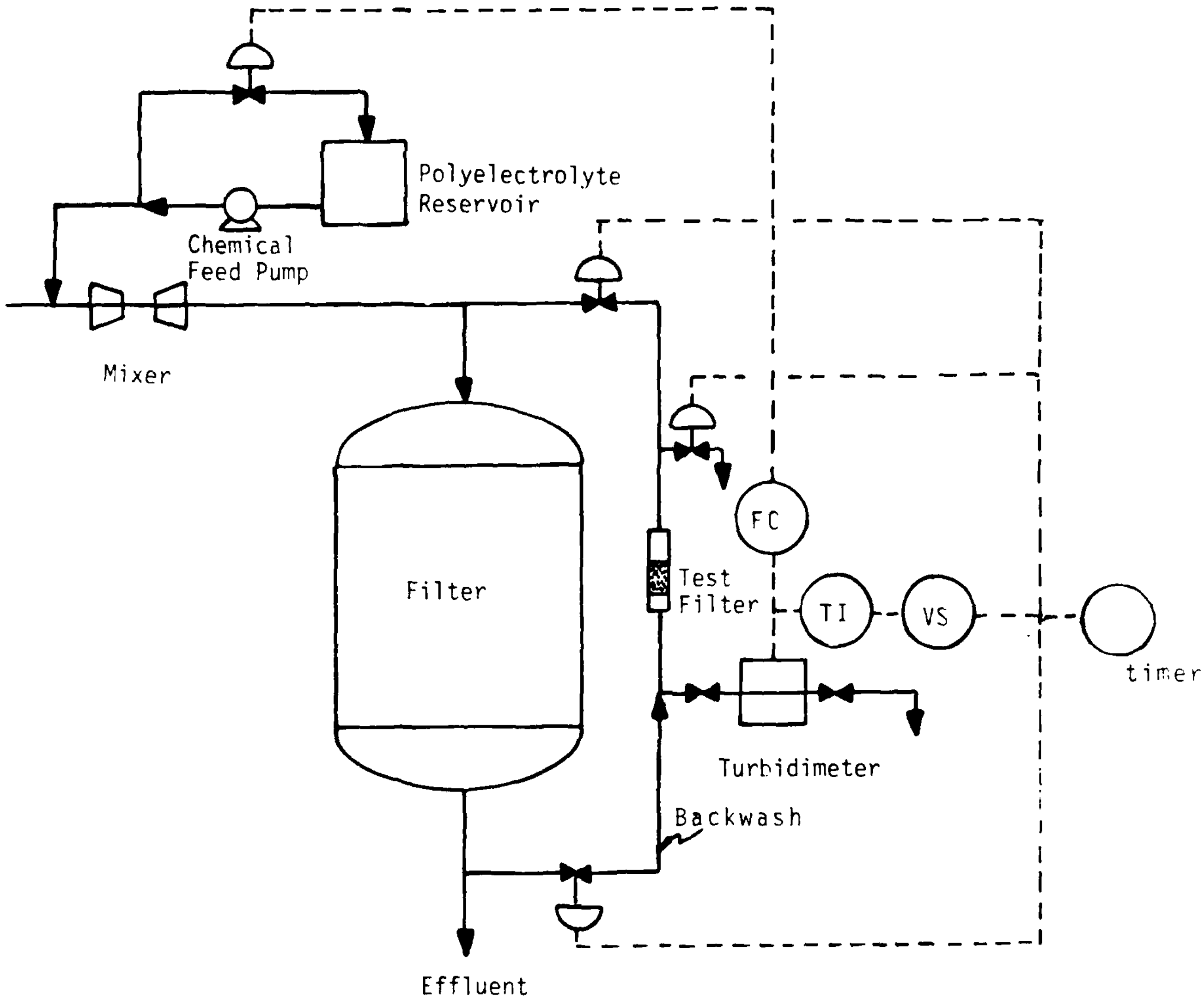
3. The dosage to the raw water influent would be continually increased until the optimum polyelectrolyte dosage was reached. This dosage would be maintained as required.

4. Any sudden surge in the effluent turbidity from the test filter, meaning a breakthrough, would automatically initiate a backwash cycle of the test filter. The high turbidity would activate a switch which would override the feed control, close the influent valve to the test filter and open the backwash influent and effluent valves to the test filter. This system would be timer controlled for backwashing, following which, the system would return to as before.

This procedure is expected to take only about 20 minutes.

Sedimentation Potential

The sedimentation potential provides another possible method for a polyelectrolyte dosage control system, as previously discussed. A semiautomatic system, as shown in Figure 15, may be possible. Similar to the filtrate turbidity method, a small sidestream unit is required. This sidestream test column would contain electrodes in a manner similar to that described in the Experimental Apparatus section of this report. The electrodes would be connected to a voltmeter. The procedure for determining the optimum polyelectrolyte dosage could be as follows:

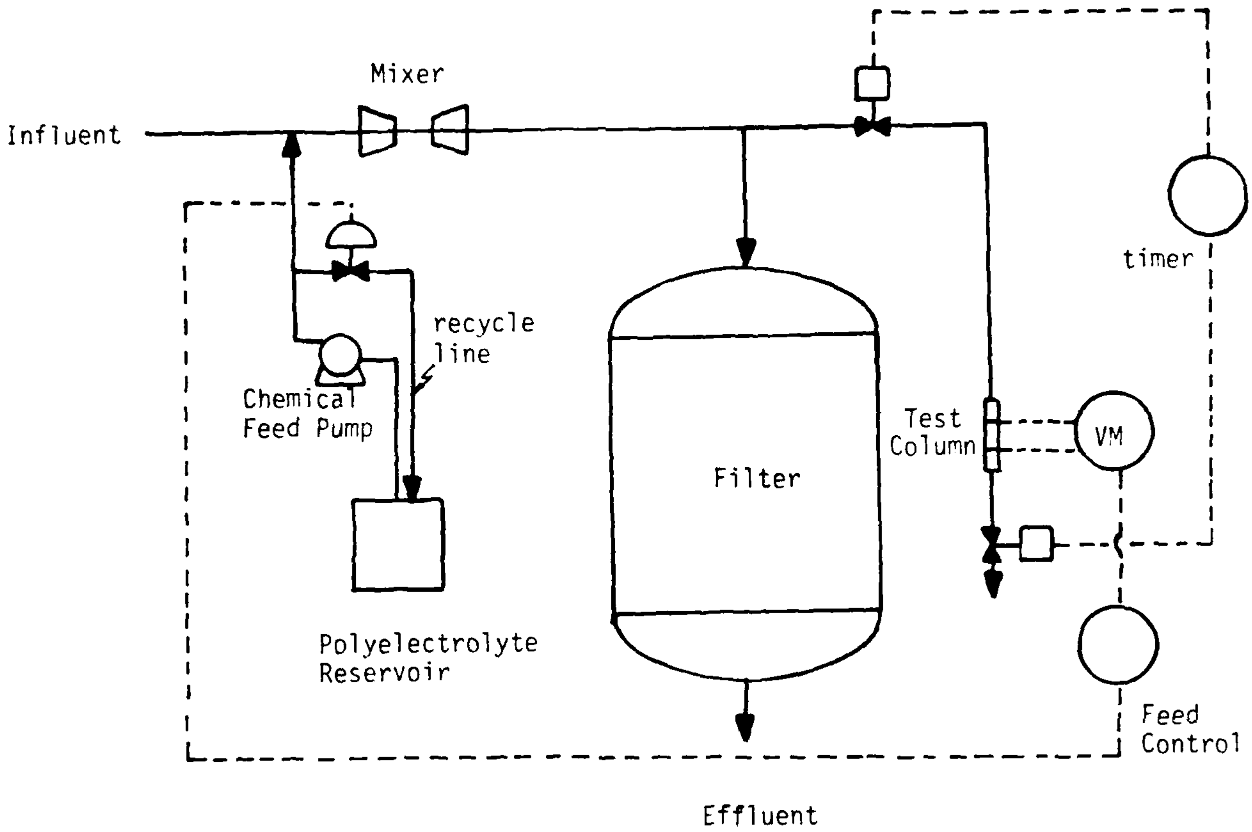


TI = Turbidity Indicator

FC = Feed Control

VS = Valve Switch

Figure 14. Conceptual design of filtrate turbidity control method.



VM = Voltmeter

Figure 15. An example setup for sedimentation potential measurements.

1. The system would be started up, as with the filtrate turbidity method, the control valve on the recycle line would be completely open.

2. A slug of raw water, with or without polyelectrolyte would be captured in the test column for approximately 2 minutes.

3. The sedimentation potential would be read at the end of the two minutes, and the polyelectrolyte dosage increased incrementally by closing the control valve on the polyelectrolyte recycle line. At the end of the test, the influent and effluent would be opened flushing the sample from the test column.

4. The maximum sedimentation potential reading, determined by finding the maximum and going one-step past, would be considered as a result of the optimum polyelectrolyte dosage. This dosage would be maintained, as required.

CONCLUSIONS

Based on the outcome of this investigation, the following conclusions concerning the five proposed methods for polyelectrolyte dosage control are offered:

(1) The sedimentation potential method is a viable alternative for dosage control. Experimental results demonstrate a consistent maximum (absolute) potential reading in the optimum polyelectrolyte dosage range. A semiautomatic system, which tests samples of polyelectrolyte-dosed raw water in a test column parallel to the main filter, may be feasible.

(2) The turbidity titration methods was not successful in predicting the optimum polyelectrolyte dosage. The experiments did not demonstrate a change in the sample turbidity after the injection of the polyelectrolyte.

(3) A good correlation between the influent turbidity and optimum polyelectrolyte dosage was not found with the synthetic or natural water samples tested. A larger number of samples could possibly give this correlation, but collection and analysis of those extra samples was outside the scope of work. Therefore, it is concluded that, based on this study, turbidity correlation is ineffective in predicting the optimum polyelectrolyte dosage.

(4) One of the criteria for determing the optimum dosage was the effluent turbidity. Therefore, this method provides one of the best means of dosage control. The determination of optimum polyelectrolyte dosage using this method is independent of the backwashing practice. A small test filter installed beside the main filter and run in parallel with automatic operation would be appropriate.

(5) The filter streaming potential technique does not give a clear indication of the optimum polyelectrolyte dosage when the water is highly heterogeneous. The method does not work when the filter media is coated with polyelectrolyte. Its application as a means of polyelectrolyte dosage control is not forthcoming.

RECOMMENDATIONS

The results and conclusions from this investigation lead to the following recommendations:

(1) Filtration turbidity should be used for a polyelectrolyte dosage control system. A more detailed design of the equipment is recommended.

(2) Sedimentation potential is another viable alternative for polyelectrolyte dosage control. This system would have to be developed, in some way, into a continuous system in order to rival the filtration turbidity method. A development study with a final detailed design of this method is recommended.

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APPENDIX A
DETAILED DESCRIPTION OF THE FILTRATION SYSTEM USED IN THIS INVESTIGATION

Sand Filter

The sand filter was designed and constructed from a 1 in. I.D. Plexglas column. At the beginning of this investigation a sand filter with a 15 in. sand bed depth was constructed as the experimental unit. Later in this investigation, a second sand filter with 3 in. sand bed was constructed for the purpose of providing a quicker response. Both columns have the same total height of 75 in. Thus, maximum heads of 60 in. and 72 in. were available for the 15 in. and 3 in. sand filters, respectively.

Five pressure taps were placed on the 15 in. sand filter throughout the length of the sand bed, with the top one placed above the sand bed and the bottom one below the sand bed. One pressure tap was placed above the sand bed for the 3 in. sand filter.

Electrodes were also inserted at various points in the sand depths to measure the filter streaming potential. Four and two electrodes were inserted in the 15 in. and 3 in. sand filters, respectively. Each electrode was constructed from platinum wires. The wires were arranged around the tube, stretched across the tube diameter and connected with a copper wire on the outside perimeter of the tube. The spacing of the pressure taps and electrodes are shown in detail for the 15 in. and 3 in. sand filters in Figure A-1.

Pump and Rotameters

A dual-channel, variable-speed Masterflux peristaltic pump was used to deliver both raw water and polyelectrolyte solution to the sand filter. Two were used to check and control the pumping rates. These rotameters had been initially calibrated and were periodically recalibrated in the course of this investigation to assure their accuracy.

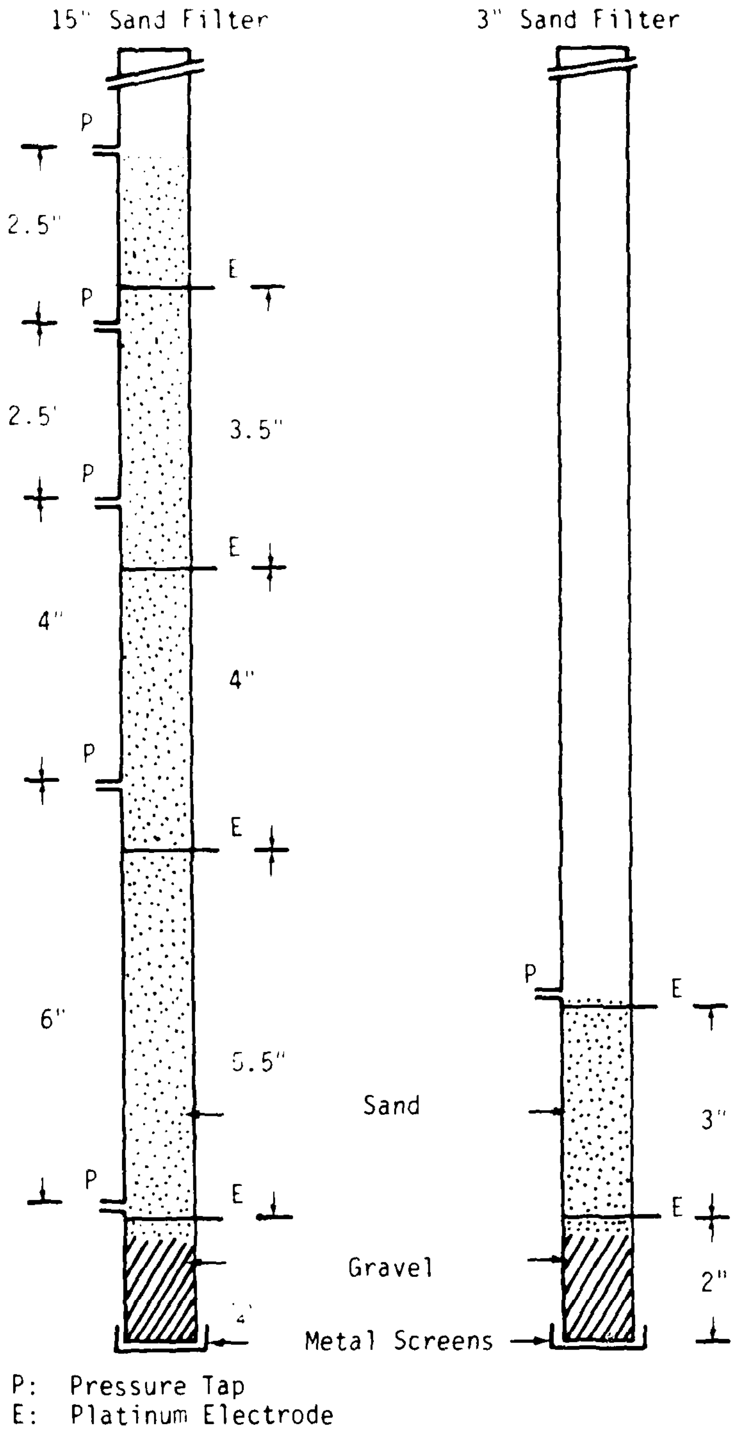

Figure A1. Details of sand filters.

Piezometer Board

A piezometer board consisting of five 0.1 in. I.D. glass tubes with a scale indicating height was placed beside the sand filter to monitor the pressure drop across the sand bed. Tygon tubing was used to connect the piezometer and the pressure tap on the sand filter.

Raw Water and Filtrate Reservoirs

The raw water reservoir was equipped with a variable-speed mixer to maintain the uniformity of the water during the filtration operation. The sand filter effluent was split into two streams. One stream was passed through a 5 micron filter paper (Whatman No. 3) placed inside a Büchner funnel. This filtration apparatus was used to determine the effectiveness of the sand filter in removing suspended solids with sizes greater than 5 microns. The other stream was collected directly and used for analysis of the sand filter performance.

APPENDIX B
MATERIAL PREPARATION

Polyelectrolyte Solution

A cationic polyelectrolyte (Cat Floc T-1, Calgon Inc.) was used for all the experiments. This is the polyelectrolyte used by MERADCOM and has been a successful as a filter aid for their applications.

The polyelectrolyte stock solution was prepared by diluting the concentrate (20% by weight) obtained from Calgon, with distilled water to a concentration of 200 mg/l. This stock solution was prepared weekly to avoid use of a deteriorated solution. The polyelectrolyte solution to be fed to the sand filter was then prepared by further dilution with distilled water.

Filter Media

Thirty mesh Ottawa silica sand was used as the filter media. The average sand particle size was approximately 0.5 mm. The sand was prewashed with distilled water a few times to remove debris. The washed sand was then placed in a 103°C oven to remove residual moisture. The dried sand was thoroughly mixed before use in the sand filter.

One-fourth in. gravel was placed under the sand bed to reduce the leakage of sand from the filter during the experiment runs. A gravel layer with a two in. depth was used.

Water Samples

Both synthetic and natural waters were used in this investigation. The preparation of these water samples are described as follows:

1. Synthetic water. Kaolin clay, humic acid, and sodium bicarbonate were added to simulate natural surface water. The humic acid was obtained from Aldrich Co., and the kaolin powder from J.T. Baker Co.

Humic acid is a common constituent of surface waters. A dosage of 5 mg/l was selected as representative of the amount of humic acid that would normally be found, and this dosage was kept constant for the experimental studies. Distilled water was the media for the synthetic water solutions, therefore, sodium bicarbonate was added to simulate natural alkalinity. A constant dosage of 75 mg/l was used which provides a bicarbonate alkalinity of around 200 mg/l as $CaCO_3$.

TABLE B-1. SYNTHETIC WATER COMPOSITION

	Dosage* mg		
Turbidity FTU	Koalin Clay	Humic Acid	Sodium Bicarbonate
43**	66.6	5	75
85	132.5	5	75
150	200.0	5	75
100	265.0	5	75

*Amount used in 1 liter distilled water

**Actual FTU values obtained

TABLE B-2. CHARACTERISTICS OF SYNTHETIC WATER PREPARED FOR THIS INVESTIGATION

Turbidity, FTU	Suspended Solids, mg/l	pH	Alkalinity as mg/l $CaCO_3$	Conductivity micromhos
43*	25	8.6	200	300
85	43	8.6	200	300
150	90	8.6	200	300
200	112	8.6	200	300

*Actual FTU values obtained

Various clays are present in the sediments of rivers. Kaolin was chosen as a representative of these clays. For this investigation, kaolin powder was added, with the humic acid and sodium bicarbonate, in dosages to create turbidities in the synthetic water of 50 to 200 F.T.U.'s. Table B-1 summarizes the dosage of the constituents required to produce a specific turbidity. Table B-2 summarizes the characteristics of the synthetic water prepared for this investigation.

2) Natural Water. Water samples were taken at three different locations in the Chicago area. These are: Des Plaines River, Lake Michigan, and Salt Creek. Water samples were taken by means of a Guzzler Model 400 hand pump (Dart Union, Co.). A metal screen was placed on the intake side of the hose to remove large debris. Generally, the water was taken near the surface except for the water samples with high turbidity which were taken near the bottom of the water body. Enough water was taken for a complete experimental run to minimize the fluctuations in water characteristics. Previous to each experimental run, the whole water sample was mixed thoroughly to resuspend the matter that settled. Then a portion of the sample was transferred to the laboratory and the remaining water was left in a sealed container. The container was stored outdoors where the ambient temperature was relatively low during the experimental period when natural water samples were used. Table B-3 summarizes the characteristics of the natural water samples used in this investigation.

TABLE B-3. CHARACTERISTICS OF NATURAL WATER USED IN THIS INVESTIGATION

Sampling Location	Turbidity FTU	Suspended Solids, mg/l	pH	Alkalinity mg/l as $CaCO_3$	Conductivity micromhos
Des Plaines River	35	30	8.2	528	890
Lake Michigan	6	4	7.4	105	220
Salt Creek	90	120	7.8	506	800

APPENDIX C
ANALYTICAL PROCEDURES

Suspended Solids

Whatman No. 3 filter papers were dried for overnight in a 103°C oven. They were then cooled in a dessicator and weighed. Suspended solids determinations were made by filtering a minimum of 25 ml of sample through a filter paper. The filter paper was then redried at 103°C for overnight, dessicated and reweighed. The increase in weight was taken as a measure of the suspended solids.

Turbidity

Hach Laboratory Turbidimeter Model 2100 was used for turbidity determinations. This technique involves the calibration of the turbidimeter against a standard solution with a known turbidity, selection of the appropriate range of turbidity reading, and measurement of sample turbidity. The turbidimeter gives a direct measurement of turbidity in FTU (Formazin Turbidity Unit). The accuracy of the instrument is within 2% of full scale (0-1000 FTU).

In the evaluation of turbidity titration technique as a possible method for polyelectrolyte dosage control, a Brice-Phoenix Light Scattering Photometer (Phoenix Precision Instrument Co.) was used to provide a more sensitive turbidity measurement. This technique involves the measurement of light scattering at 90 degress through a standard 40 x 40 mm semi-octagonal sample cell. The direct readout from the instrument was in millivolt (mv). The wavelength chosen was 436 mμ. Distilled water was used to calibrate the photometer which gave zero mv readout.

pH

pH was measured using a Beckman Model SS-1 pH Meter (Beckman Instrument Co.)

Alkalinity

Alkalinity was determined potentiometrically in accordance with Standard Method (1975) where 50 ml samples were titrated to a pH of 4.5 by addition of 0.02 N sulfuric acid. Results were expressed as mg/1 as $CaCO_3$.

Conductivity

The Zeta-Meter was used for conductivity measurements. The sample was placed in the Riddick Cell, the anode and cathode attached and a voltage equal to the cell constant was impressed. The conductivity was read directly off the microammeter. The relationship is as follows:

$$\text{Specific Conductance (micromhos/cm)} = \frac{K \cdot I}{E} \qquad \text{(C-1)}$$

where K = cell constant (=65)

I = current in microamps

E = volts

Turbidity Titration

The procedure for determining the effectiveness of the turbidity titration is as follows:

1. A 500 ml water sample was placed in a 1 liter beaker. The solution was kept in suspension using a magnetic stirrer. The turbidity was recorded for the sample using both Hach Model 2100 Turbidimeter and Brice-Phoenix Light Scattering Photometer.
2. A pre-determined polyelectrolyte dosage was added to the beaker and allowed to mix for about 10 to 15 seconds.
3. The turbidity of the sample was read immediately after mixing.

Sedimentation Potential

Sedimentation Potential was determined as follows:

(1) A 500 ml water sample was transferred to a 1 liter beaker and agitated with a magnetic stirrer.

(2) Polyelectrolyte solution was metered into the sample via a titration buret to give a desired concentration.

(3) Water sample was allowed to mix with polyelectrolyte for 10 to 15 second after the addition of polyelectrolyte.

(4) Sample was then transferred to a 1 in I.D. Plexglas column equipped with two platinum electrodes 15 in apart. Enough water was added to the column to cover the top electrode.

(5) A Fluke Model 8020A Multimeter was attached to two electrodes and the millivolt readings were taken at 30-second intervals for the first 3 minutes and then at 1-minute intervals for 7 minutes.

The multimeter used in this investigation had been calibrated against a Keithley Electrometer previous to the measurement of sedimentation potential.

Filter Streaming Potential

Filter streaming potentials were taken by attaching a Fluke Model 8020A Multimeter to two of the platinum electrodes placed on the sand filter at a time and taking the millivolt reading.

APPENDIX D

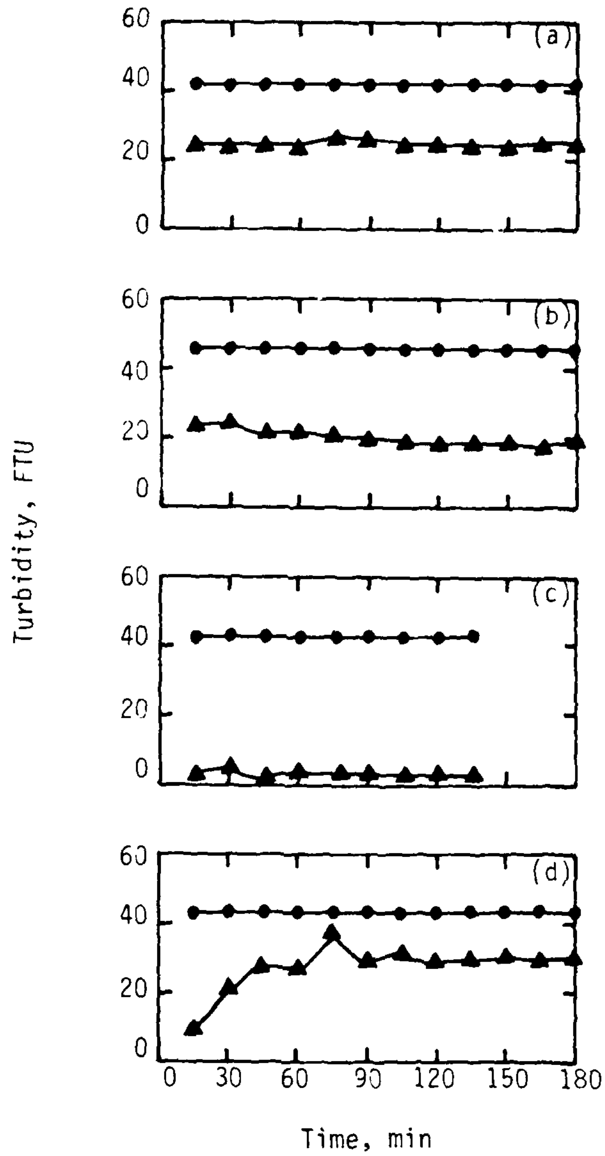

Figure D1 The effluent turbidity vs. time. Synthetic water. Polyelectrolyte dosages:
(a) 0 mg/l, (b) 1 mg/l, (c) 2 mg/l, (d) 5 mg/l.
(●): Influent (▲): Effluent

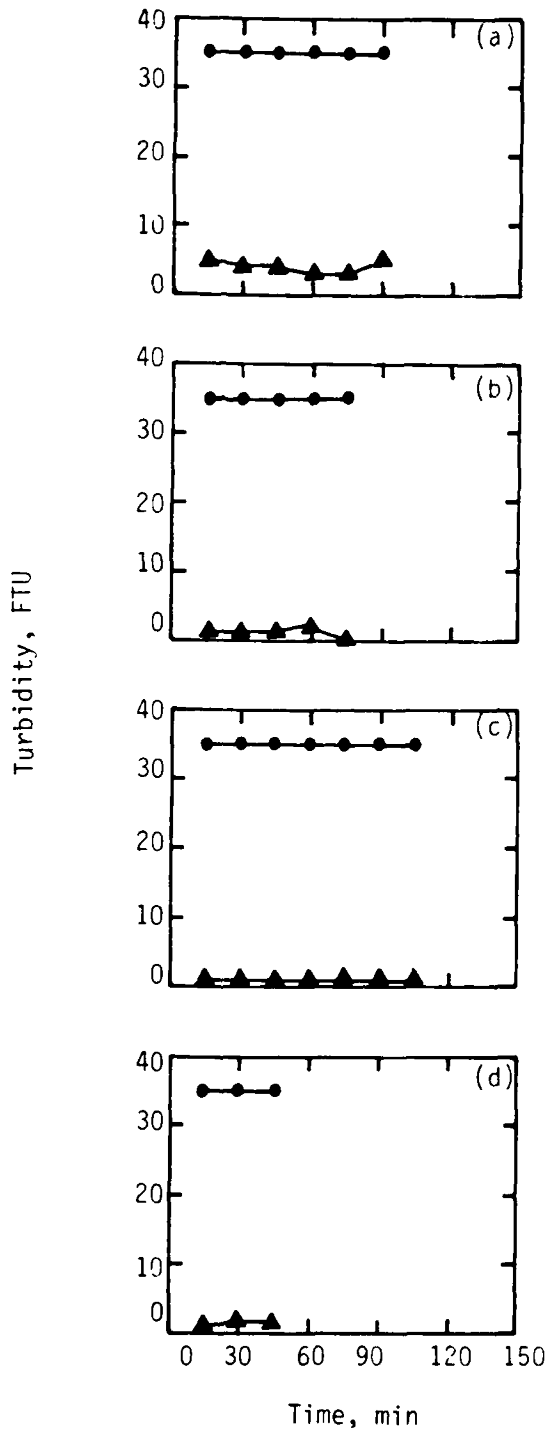

Figure D2 Effluent turbidity vs. time. Des Plaines River water. Polyelectrolyte dosages:
(a) 0 mg/l, (b) 0.5 mg/l, (c) 1 mg/l, (d) 1.5 mg/l.
(●): Influent (▲): Effluent

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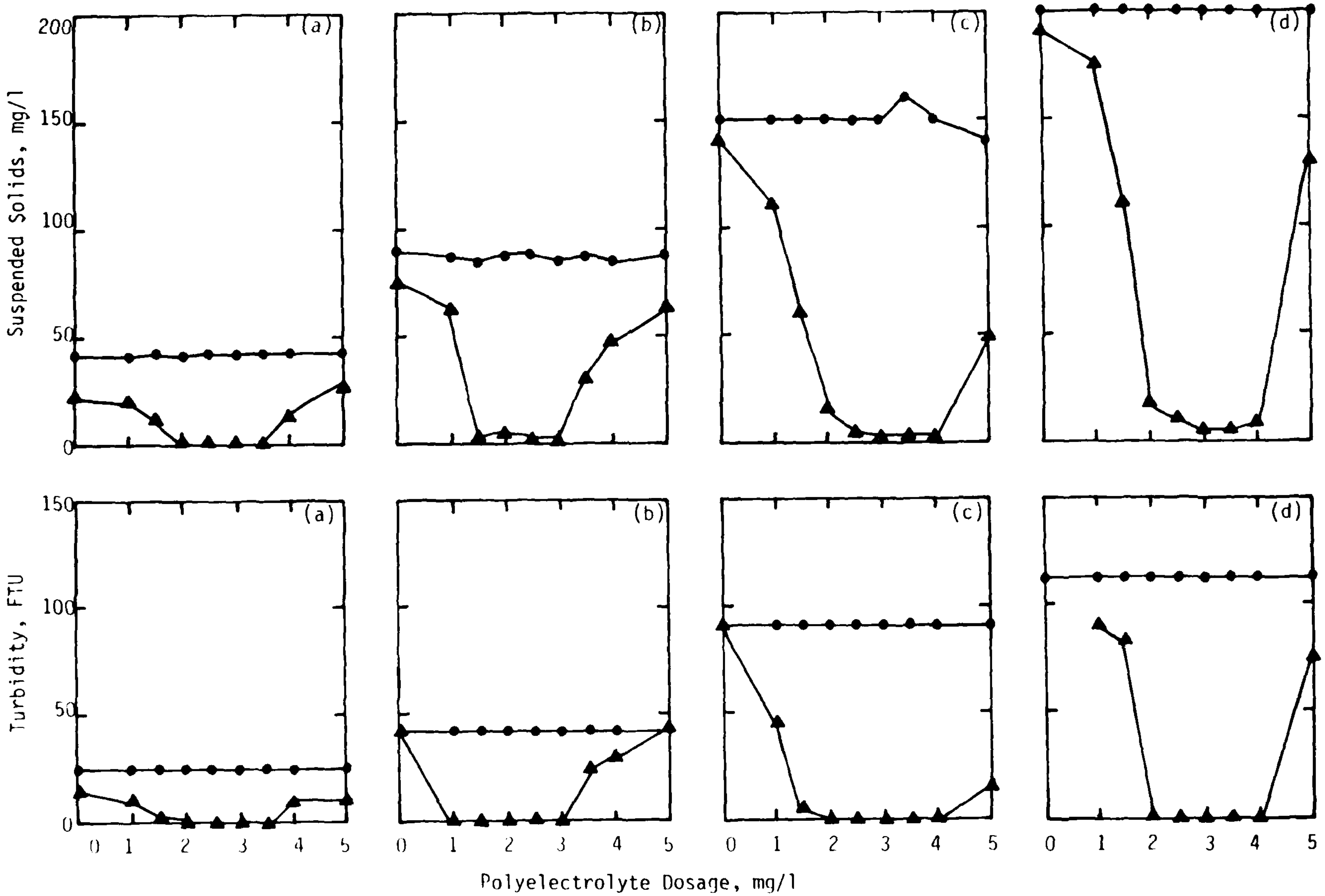

Figure D- Turbidity and suspended solids removals vs. polyelectrolyte dosages. Synthetic water.
(a) 43 FTU, (b) 85 FTU, (c) 150 FTU, (d) 200 FTU.
(●): Influent (▲): Effluent

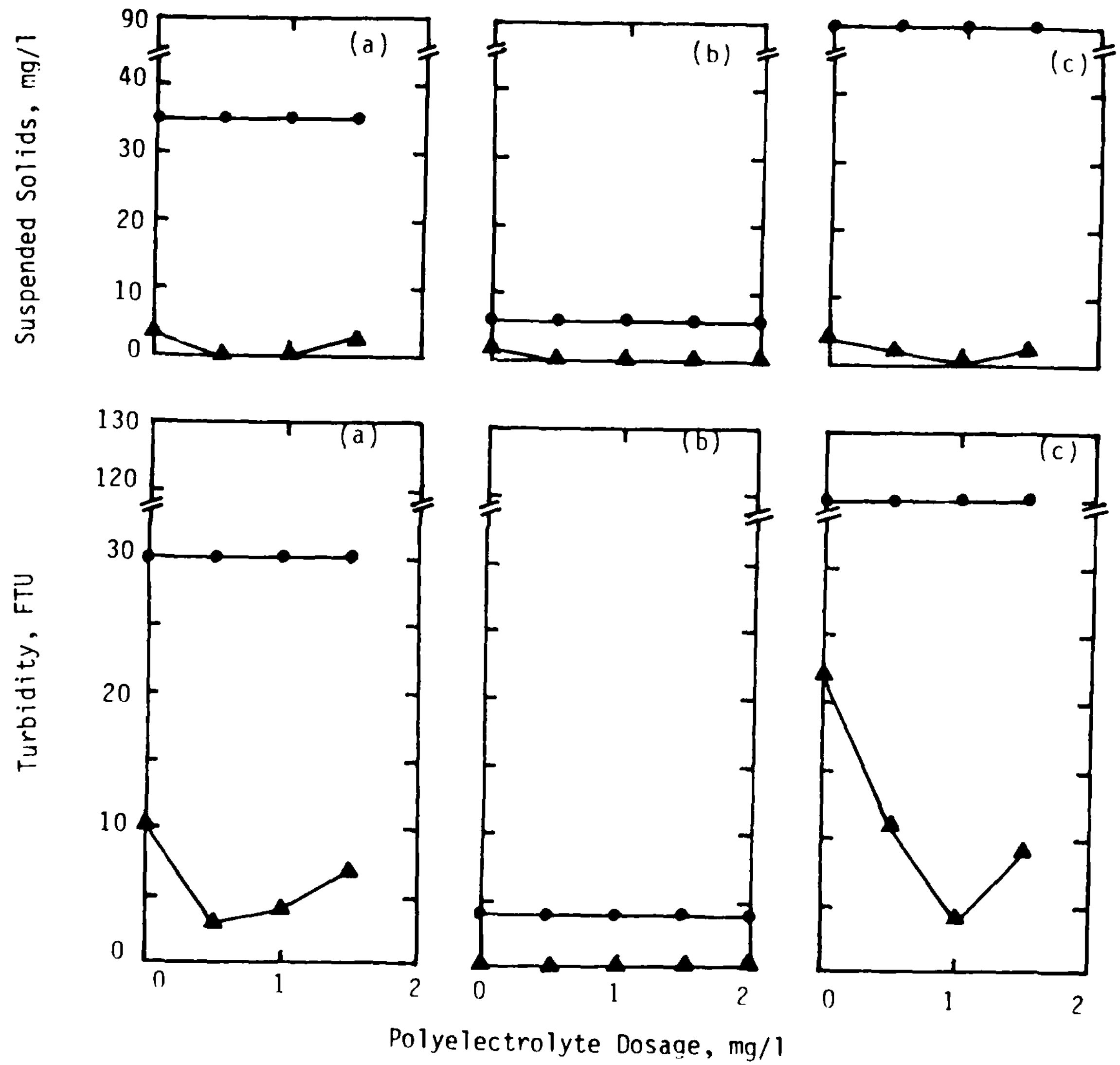

Figure D4 Turbidity and suspended solids removals vs. polyelectrolyte dosages. (a) Des Plaines River, (b) Lake Michigan, (c) Salt Creek. (●): Influent (▲): Effluent

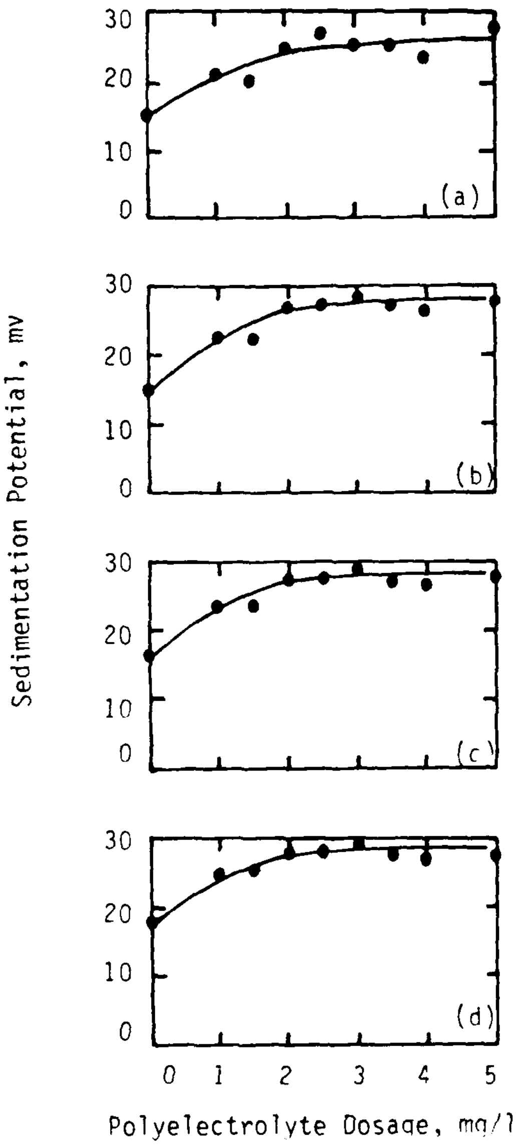

Figure D5 Sedimentation potential readings at various polyelectrolyte dosages. Synthetic water (Influent Turbidity = 43 FTU) (a) 1 min, (b) 2 min, (c) 5 min, (d) 7 min.

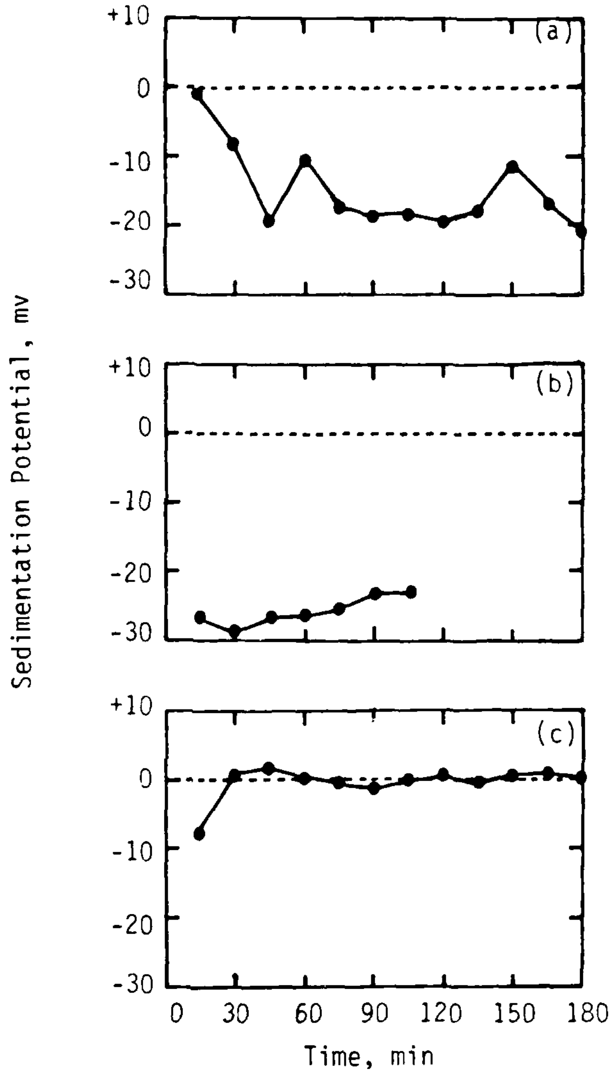

Figure D6 Filter streaming potential readings vs. time. Synthetic water (Influent Turbidity = 43 FTU). Polyelectrolyte dosages: (a) 1 mg/l, (b) 2.5 mg/l, (c) 5 mg/l.

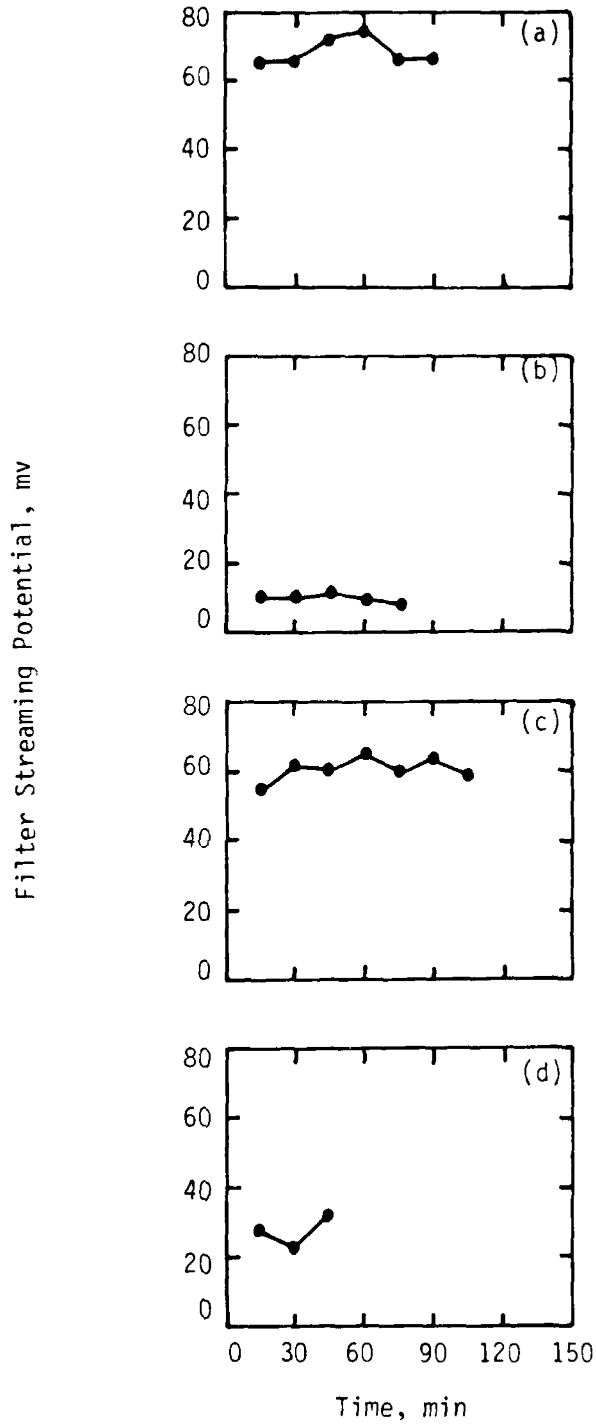

Figure D7 Filter streaming potential readings vs. time. Des Plaines River (Influent Turbidity = 35 FTU). Polyelectrolyte Dosages: (a) 0 mg/l, (b) 0.5 mg/l, (c) 1.0 mg/l, (d) 1.5 mg/l.

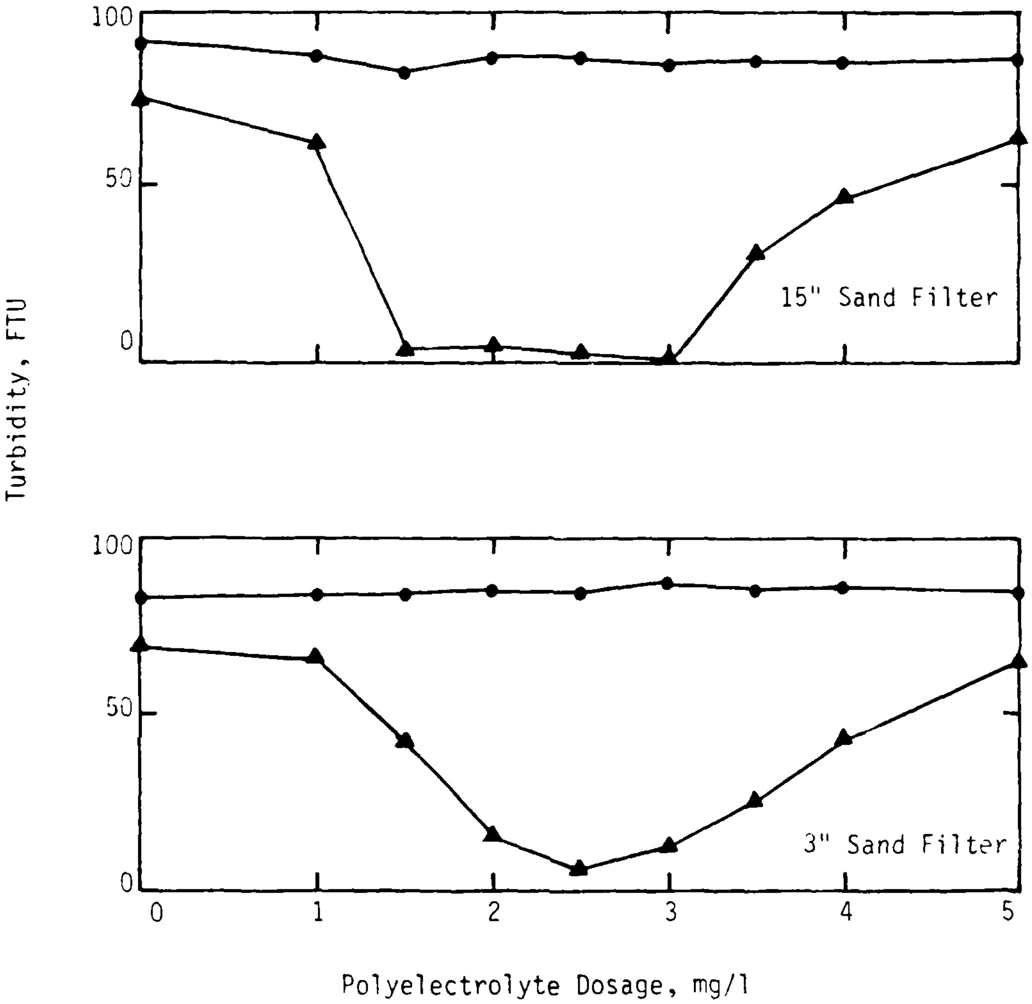

Figure D8 Comparison of turbidity removals with two sand bed depths.
(●): Influent
(▲): Effluent

APPENDIX E

TABLE E1 EFFLUENT TURBIDITY (FTU) VALUES
AT DIFFERENT POLYELECTROLYTE DOSAGES (15" SAND FILTER)

Water Sample	Polyelectrolyte Dosage, mg/l									
Synthetic Water	0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0
43*	[illegible]	-	21	12	2	2	2	1	14	27
85	74	-	62	3	4	2	2	30	47	63
150	140	-	110	60	16	5	3	3	2	48
200	190	-	175	110	17	9	5	5	8	130
Natural Water										
Des Plaines River (35)*	3	1	2	3	-	-	-	-	-	-
Lake Michigan (6)	2	<1	<1	<1	<1	-	-	-	-	-
Salt Creek (90)	4	3	5	1	-	-	-	-	-	-

*Influent turbidity in FTU

TABLE E2 EFFLUENT SUSPENDED SOLIDS CONCENTRATION (mg/l) VALUES AT DIFFERENT POLYELECTROLYTE DOSAGES (15" SAND FILTER)

Water Sample	Polyelectrolyte Dosage, mg/l									
Synthetic Water	0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5
25*	15	-	10	3	nil	nil	nil	nil	10	10
43	43	-	nil	nil	nil	nil	nil	25	33	43
90	90	-	45	5	nil	nil	nil	nil	nil	15
112	-	-	90	85	nil	nil	nil	nil	nil	75
Natural Water										
Des Plaines River (30)*	10	3	4	7	-	-	-	-	-	-
Lake Michigan (4)	nil	nil	nil	nil	-	-	-	-	-	-
Salt Creek (120)	22	11	4	9	-	-	-	-	-	-

*Influent suspended solids concentration in mg/l

TABLE E3 LENGTHS OF FILTER RUNS (MINUTES) AT DIFFERENT POLYELECTROLYTE DOSAGES (15" SAND FILTER)

Water Sample	Polyelectrolyte Dosage, mg/l									
Synthetic Water	0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0
43*	180	--	180	180	130	105	135	120	180	180
85	180	--	180	105	75	75	105	180	180	180
150	180	--	180	180	90	60	90	75	105	180
200	180	--	180	180	75	45	60	75	60	180
Natural Water										
Des Plaines River	80	75	105	45	--	--	--	--	--	--
Lake Michigan	180	180	125	180	--	--	--	--	--	--
Salt Creek	30	20	30	20	--	--	--	--	--	--

* Influent Turbidity in FTU

TABLE E4 EXPERIMENTAL RESULTS ON TURBIDITY TITRATION

(1) Hach Turbidimeter (in terms of FTU)

Water Sample		Polyelectrolyte Dosage, mg/l									
Synthetic Water		0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0
43*	Before	43	-	43	43	43	43	43	43	43	43
	After	43	-	42	43	42	43	43	42	43	43
85	Before	85	-	85	85	85	85	85	85	85	85
	After	85	-	84	85	85	85	85	84	86	85
150	Before	150	-	150	150	150	150	150	150	150	150
	After	150	-	150	150	150	150	150	150	150	150
200	Before	200	-	200	200	200	200	200	200	200	200
	After	200	-	205	200	200	200	200	200	200	200
Natural Water											
Des Plaines River	Before	35	35	35	35						
	After	35	35	35	35						
Lake Michigan	Before	6	6	6	6	-	-	-	-	-	-
	After	6	6	6	6	-	-	-	-	-	-
Salt Creek	Before	90	-	90	90	90	90	90	90	90	90
	After	90	-	89	91	90	90	90	90	90	89

(2) Brice-Phoenix Photometer (in terms of mv)

Water Sample		Polyelectrolyte Dosage, mg/l									
Synthetic Water		0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	5.0
85*	Before	51.5	-	51.5	51.5	51.5	51.5	51.5	51.5	51.5	51.5
	After	51.0	-	51.5	52.0	51.5	51.6	51.4	51.2	51.5	51.5
150	Before	62.0	-	62.0	62.0	62.0	62.0	62.0	62.0	62.0	62.0
	After	62.0	-	62.1	62.5	61.8	61.8	62.1	62.1	62.0	62.0

*Influent Turbidity in FTU

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